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Translation

FUNDAMENTALS OF ERGONOMICS

By

V.P. Zinchenko and V.M. Munipov

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INTRODUCTION

Socialism is the first in history to pose the question of working man not simply as a worker, but as an individual whose comprehensive development becomes a mandatory prerequisite for growth of productive forces and progress of society as a whole. This approach also expresses the objective tendency toward drastically increasing the role of the human factor in national production, as determined by the scientific and technological revolution.

It is being a pressing need for economic development of the Soviet State to create conditions that favor comprehensive development of skills and creativity of the Soviet people, of all workers, during this period of building of communism. Meeting many of the vital demands of the working people is directly or indirectly related to the specific industry, in which they are engaged. The Soviet State is concerned about improving working conditions and safety, scientific organization of labor, reducing and subsequently eliminating entirely heavy physical labor, on the basis of complex mechanization and automation of industrial processes in all sectors of the national economy, and this is spelled out in Article 20 of the first new basic law, the Constitution of the USSR.

Development of physical production on the basis of increased efficiency and quality is the chief route toward reaching the basic and long-range goals of the economy of a developed socialist society. High efficiency of production is an exceptionally multifaceted problem. There is a wide range of factors related to scientific and technological progress proper, to refinement of the system of socialist management, continued development of socialist democracy, growth of professional and ideological-theoretical training of workers upon which depends attainment of this goal. All these factors are reflected in the immediate work process, in the labor of people, in some specific form or other in various branches of the national economy and in some specific combination.

Increasing the efficiency and quality of labor is one of the most important means of attaining high efficiency of production. In our country, the movement toward high efficiency and quality of work has become genuinely nation-wide. It is imperative to conduct theoretical scientific studies of problems of human labor and its role in modern industry for continued and better solution of this problem.

Labor is a social phenomenon. But since any labor is based on mental and physiological processes, the disciplines dealing with human performance and functions play a large role in solving problems of increasing the productivity of labor.

With the development of industry, changes occur in conditions, methods and organization of human labor; there are substantial changes in functions, role and place of man in the labor process and, accordingly, different aspects of scientific research on human labor move to the fore at different stages of history. Predominantly an energy-related approach to the study of this process, due to prevalence in the past of manual labor, is inherent in studies dealing with physiology of labor, which appeared in the 19th century. At the present time, industrial physiology, which has undergone a certain evolution, deals with the patterns of physiological processes and distinctions of regulation thereof in the course of human labor, and it backs up with the appropriate data the means of organizing the labor process that would be instrumental in maintaining human performance on a high level for a long time. Industrial hygiene, a preventive discipline that deals with the effects of the labor process and industrial environment on workers for the purpose of elaborating sanitary-hygienic and therapeutic-preventive measures to provide optimum working conditions, good health status and efficiency of man, is closely linked with industrial physiology.

At the start of the 20th century, when technological progress resulted in the appearance of complicated types of labor (driving a car, operating a locomotive, etc.), which made some serious demands for high speed reactions, perception and other mental processes of man, there was a strong impetus for development of industrial psychology. This scientific discipline deals with the psychological distinctions of human labor for the purpose of increasing productivity of labor and forming personality traits of professional importance.

Differentiation of disciplines dealing with labor has played and continues to play a beneficial role in development of our knowledge about it. In the course of such differentiation, research methods were developed and refined, some important patterns were demonstrated, the principles were formulated of rational organization of different aspects and elements of the work process.

At the same time, as knowledge accumulated, contacts between disciplines inevitably occurred. Industrial hygiene was compelled to turn to the data in industrial physiology and psychology, industrial psychology had to turn to hygiene and systems analysis, etc. And this is understandable, since in reality labor is not the sum of scattered elements, but something whole. In actual performance of labor, the psychological components are not separated from physiological or social ones. Moreover, one cannot understand human endeavor without studying it in its interaction with the operation of technical devices which man uses to solve a given labor problem.

In the late 1940's and early 1950's, a need arose for an integral system of conceptions about working man, his labor performance, his correlations with machines and the environment, on the basis of the accumulated data about labor. Without such a system it was difficult to further develop special disciplines and to make effective use of the accumulated knowledge in practice.

But, of course, it is not only a matter of the logic of development of disciplines. The objective processes that were induced by the scientific and technological revolution played a decisive role in the inception of the systems approach to the study of working man and his labor activities. Qualitative changes are taking place in the content of labor, and the structure of occupations established over the centuries is undergoing a transformation. Automation of industry, which is radically altering the content of human labor, synthesizes many labor functions in man's work, which were previously separated. Truly human creative functions are demonstrable more and more in labor activity. The present era of revolutionary transformations, the era of formation of a new communist system, internally linked with revolutionary changes in science and technology, fills with new meaning the thesis, according to which "in the historically distant future, we are dealing with one of the most radical transformations, of transformation of the entire existing means of human endeavor" (see [44, pp 152-153] in bibliography for Chapter I).

The contradiction of scientific and technological progress consists of the fact that, along with enormous positive results, it also brings certain negative social consequences (see [1]). In modern industry, which is extensively supplied with complex technological systems, drastically greater demands are made of man, which compel him to sometimes work at maximum psychophysiological capacity and under extremely complicated working conditions. And man is responsible for the efficient function of large systems for the control of production, transport, communications, space flights, etc., and an error on his part could lead, in some cases, to very serious consequences. Technological progress has raised the "man-machine" problem most acutely. Man's capabilities are expanding because of development of tools of labor, but the tools often turn out to be so complex or unrationally designed that it is difficult to use them. With the development of technology, the problem arose of conforming the design of machines and their operating conditions to the characteristics of working man. The machine must be convenient in all respects for the man who services it; it must correspond to his psychophysiological characteristics.

At the present time, technical equipment and technological processes are become more complex (structurally and functionally), and control of large complexes is undergoing centralization. Analysis of the efficiency of automated control systems shows that it is expressly operator error that often is the cause of malfunctions in the system. The trends in development of modern industry are such that the main designing difficulties in the next decades will probably be related to determination of the ways and means of optimizing interaction between man and machines, rather than research on the characteristics of equipment. In the course of designing complicated complexes, the problem arises of predicting the performance of man (group of people), and it cannot be solved on the basis of the rule: "let us build the machine, then we'll see why it does not work," as we have seen from the sad experience of building certain expensive systems.

Previously, every version of a work tool could have been tested, literally for centuries, through human endeavor and constantly refined. But now, society does not have the time for this (for example, in the last few decades, there have been three successive generations of computers). At the same time, the cost of technical equipment and the "price" of human error in controlling complex systems have increased drastically. For this reason, when designing new technology and updating existing technology, it is imperative to take into consideration in advance and as thoroughly as possible the capabilities and distinctions of the people who will be using it.

The parameters of the physical industrial environment must also conform with the characteristics of man, and only then can one expect high efficiency of his labor. In some types of industry, in the course of the work day man is compelled to stay in rooms with artificial light, in the presence of a certain chemical composition of air that is required by technology. Sometimes he has to work at high atmospheric pressure and sometimes at low pressure. Some occupations involve the necessity of enduring high accelerations, altered gravity, noise, vibration, etc. Development of new machines and development of new technological processes mean that a new environment is developed for man. Sometimes, this environment is a combination of natural and artificial conditions, and sometimes it is entirely artificial. For this reason, when creating a new machine, one should not deal simply with a machine as such, but with the "man-machine-industrial environment" system.

A complex, systemic approach to the study of the above-mentioned problems was the methodological basis for the birth of a new scientific discipline, ergonomics. Of course, the above problems had been raised to some degree or other before, and some degree of solution was obtained through studies in industrial psychology, physiology and hygiene. In the course of these studies, there was intensification of interaction between these disciplines, and it became necessary for some of them, for example, industrial physiology and psychology, to penetrate into one another.

Studies and design man-machine-industrial environment systems created the prerequisites for combining the engineering disciplines, human sciences and those pertaining to his work activity, and caused the appearance of a new psychophysiological problem. Ergonomics was formed on the borderline between psychology, physiology, industrial hygiene and engineering sciences. All of them, with the exception of engineering sciences, study the same object, but they consider working man from different points of view and use different methods.

The set of human sciences is playing an ever increasing role in studies of problems of development and control of modern industry, of increasing its effectiveness. Formation of ergonomics reflects the need for social production to synthesize the achievements in socioeconomic, natural and engineering sciences as applied to the tasks of studying and planning work processes. It was stressed at the 25th CPSU Congress that "New opportunities for fruitful research, both general theoretical, basic, and applied, are opening up on the boundary between different sciences, in particular natural and social sciences. Full use must be made of them" [3, p 87].

While previously the development of technology was implemented primarily by advances in physicomathematical, chemical and engineering sciences, at the present time data from biological, psychological and socioeconomic sciences are being used more and more to solve problems arising in engineering [21]. "It is not technology by itself and not man as the subject of production that are becoming the subject of scientific research in the area of work activity, but conformity of his physical and mental capabilities, aesthetic taste and other social qualities with the properties of modern technological systems" [43, p 62.

The inception of ergonomics is related to development of a contradiction within a real object, namely technology which, as a phenomenon with a natural foundation, has a relatively independent logic of function and development, but as an element of the work process it functions in the same system with man and develops in accordance with the laws of his labor. "The existence of technology outside the body creates the possibility of infinite technological progress, free of the limitations of the human body. But no matter how much technology develops, it will always remain as the "continuation" of man's natural organs, his hands and brain. The infinity of technological progress and the possibility in principle of "relegating" the work functions of the individual to technology are limited by man's goals to its purpose as a means of human labor" [40, p 55].

Certain problems of quality of labor, which is interpreted rather broadly, are developed in ergonomics. Quality is an integral characteristic of a given form of labor, in which determination is made of indices of quality and quantity of products as related to labor performed, the psychological and physiological "price" of work, as well as health and development of the worker's personality. The correlation and interdetermination of all the above components form an integral system of quality of a certain form of labor, which has a multilevel structure.

Ergonomically oriented work is referable to the category of applied research that implements integration of science and industry. Development and implementation of ergonomic principles and recommendations are becoming a component of a broad program of measures directed toward creating new and updating existing technology, toward further alleviation of labor and ameliorating conditions from the standpoint of health, as well as increasing its efficiency and quality. Ergonomics is making a certain contribution to implementation of a multilevel and long-term program for the transition from safety practices in engineering to safe engineering. At the same time, use of the achievements in ergonomics makes it possible to increase substantially the attractiveness of labor. "Man spends a significant and most active part of his life at work. Hence, the specifics of the requirements made by various social groups of his labor activity. These are requirements of the content of labor, as well as of opportunity for self-expression and self-assertion these are requirements of working conditions and schedule, which would permit preservation of health and performance of various roles and functions aside from work and, finally, these requirements refer to a certain material reward. The attractiveness of work is determined by the extent to which these requirements are met" [6, 84].

In these times of faster and faster renewal of the existing store of knowledge and, accordingly, engineering and technology, the ergonomic refinement of different aspects of production must be included in the program of man's education (in the broad sense) as an internal condition for its implementation, and this would mean not only more effective solution of problems of adapting technology to man, but active formation of man's capabilities in accordance with the requirements imposed upon him by technological progress and the opportunities offered to him with the development of technology.

The trends of development of ergonomics are making it necessary to apply the methods and criteria it develops to any area of human endeavor, both in industry and everyday life. The subjective area of research and planning in ergonomics is also expanding as a result of inclusion of various objects that form the objective [object-related] and spatial environment of human life, including the elderly and physically handicapped. Today, one of the newest areas of application of the results of ergonomic research is the design of technically intricate products that improve living conditions. Ergonomics, in close cooperation with aesthetic styling in engineering, provides for the high consumer quality of these products, their attractive appearance and convenience in use.

At this time of scientific and technological revolution, ergonomics is acquiring increasing social and economic significance, aiding in the most effective use of its achievements in the interests of man and society. Ergonomics is called upon not only to help create optimum working, living and recreational conditions for man, but to form new cultural values, to create conditions for comprehensive development of man.

This textbook was written on the basis of our 20 years of experience in the field of industrial psychology, engineering psychology and ergonomics. We used the course of lectures delivered at Moscow State University imeni M. V. Lomonosov. This book also reflects the results of numerous studies in general and experimental psychology conducted in the department of industrial and engineering psychology of Moscow State University and department of ergonomics of the All-Union Scientific Research Institute of Aesthetic Styling in Engineering [VNIITE], under the USSR State Committee for Science and Technology.

We have summarized here material from publications that we have written or written under our guidance: "Engineering Psychology," Moscow, published by Moscow University, 1964; "Human Engineering Specifications for Control Systems," Moscow, published by VNIITE, 1967; "Ergonomics. Works of VNIITE," issues 1-17, Moscow, published by VNIITE, 1970-1979; "Ergonomics. Principles and Recommendations," issues 1-7, Moscow, published by VNIITE, 1970-1975; "Ergonomic Bases for Organization of Labor," Moscow, Ekonomika Publishing House, 1974; "Microstructural Analysis of Executive Performance," Moscow, published by VNIITE, 1975; "Psychometrics of Fatigue," Moscow, published by Moscow University, 1977; "Pressing Ergonomic Problems. Human and Animal Physiology," Vol 21 ("Advances in Science and Technology," VINITI [All-Union Institute of Scientific and Technical Information], USSR Academy of Sciences), Moscow, published by VINITI, 1978; "Current Status of and Trends in Development of Ergonomics," Moscow, published by VNIITE, 1978. We also used the set of standards in "Man-Machine Systems" and "Intersectorial Specifications and Standards for Scientific Organization of Labor to Be Considered in Designing New and Remodeling Existing Enterprises, in Developing Technological Processes and Equipment," Vol 1, Moscow, 1978, published by the Scientific Research Institute of Labor, USSR State Committee for Labor. We were directly involved in preparing these materials on engineering standards.

This book also deals with some of the preliminary results of scientific and technological collaboration of CEMA member nations in the area of ergonomic problems, which was implemented with the cooperation of the Coordinating Center opened at VNIITE.

We were fortunate enough to work on the problems with which this book deals under the guidance of and in collaboration with a number of outstanding Soviet scientists: S. G. Gellershteyn, F. D. Gorbov, P. I. Zinchenko, A. N. Leont'yev, V. D. Nebylitsyn, D. Yu. Panov and E. G. Yudin. They all served science selflessly, were instrumental in the creation and development of new directions in the study and planning of work activity, and they made an enormous contribution to elaboration of new methodological principles for analysis thereof.

We wish to express our deep appreciation to the many coworkers and colleagues whose personal participation, advice and critical comments were of substantial help in working on this book.

There is as much responsibility as difficulty in preparing a textbook. The difficulties are multiplied when dealing with a textbook on an interdisciplinary, complex and new area of scientific and practical endeavor. For this reason, these authors will be grateful for criticism, comments and wishes pertaining to future improvements in this textbook, and they should be addressed to the Moscow State University Publishing House.

CHAPTER I. ERGONOMICS AND ITS PLACE IN THE SYSTEM OF SCIENCES

1. Subject and Tasks of Ergonomics

Problems of defining the object of ergonomics and the aspects of this object that it studies, i.e., demonstration of the subject of its studies, are particularly important for a developing scientific discipline. Such definitions are usually constructed on the basis of empirical data and, to a significant extent, from the actual scientific contribution made by specialists involved in this discipline [5, 13, 23, 28, 49, 51, 53, 54].

Ergonomics is a scientific discipline that studies man (group of people) in a complex way, under concrete conditions of his (their) work, which is related to the use of machines (technological means). Man, machine and the environment are considered in ergonomics as a complicated functional entity, in which the leading role belongs to man. Ergonomics is both a scientific and planning discipline, since its task includes development of methods of taking into consideration of human factors when updating existing machines and technology and developing new ones, as well as appropriate working (activity) conditions.

Interest in "man-machine" systems emerged in the middle of the 20th century; it was attributable to the fact that diverse complex systems for the control of industry, transport, communications, space flights, etc., the efficient function of which is largely determined by the performance of man, included in them as the leading element. The combination of human capacities and machine capabilities (or capabilities of an aggregate of technological means) improves substantially the efficiency of control. In spite of the joint performance of control functions by man and machine, each of the two elements of this complex system is governed by the rules [patterns] inherent in the system, and the efficiency of operation of the system as a whole is determined by the degree to which the distinctions inherent in man and machine, including limitations and potential capabilities, were determined and taken into consideration when the system was created.

The concrete activity of man (or group of people) using machines (technological means) is the subject of ergonomics, while the "man (group of people)-machine (technological means [equipment]) system" is the object of its study."* Optimization of such systems requires a complex approach. "Ergonomics is science plus technology [engineering]. The subject of ergonomics as a science is the activity of man the worker and man the consumer. The objective of ergonomics as technology is to optimize working conditions" [16, p 14].

Ergonomics considers the technological and human aspects in their inseparable relationship. Ergonomics could, probably, exist and make certain achievements at the juncture of industrial psychology, physiology, hygiene, and anatomy; however, genuine progress and its practical value are determined by the level of synthesis in it of the human and technological aspects. Moreover, the desire to disclose the patterns of this synthesis characterizes ergonomics as a new discipline of a special type. To solve applied problems of ergonomics implies movement in two directions simultaneously: from the requirements of man to technology and conditions of its function, and from the requirements of technology and its operating conditions to man. Both these directions are interrelated, and optimum solutions are usually at the points of their intersection. In order to find such optimum answers, it is not enough to make use of individual recommendations of industrial psychology, physiology and hygiene, anthropometry and others. It is imperative to coordinate these recommendations with one another, to subordinate and tie them in a single system of requirements for a certain type of specific activity and conditions under which it is performed. It is knowledge (or conceptions) of man's activity as a whole that is important, rather than separate functional capacity to perceive, think and act, and it is imperative to take into consideration all of the circumstances upon which depends the success of man's activity.

The ergonomic nature of technology is an integral feature, the most general indicator that blends the hierarchic structure of properties and indicators of lower levels. This integral characteristic evolves from a number of ergonomic properties of technology: capacity to be controlled, serviced, learned and inhabited. The first three are characterized by the limitations on inclusion of technology in the corresponding forms of activity of man (group of people). Habitability of technology is characterized by approximation of conditions (the environment) of its operation with biologically optimum environmental parameters, with which a working man is provided with normal development, good health and a high degree of fitness for work, and which also minimize or eliminate the deleterious consequences of its operation to the environment. Every ergonomic property of technology, in turn, emerges from a number of complex indices which represent different, but

*Hereafter, for the sake of brevity, we shall refer to the man-machine system (MMS).

interrelated aspects of these properties. The complex ergonomic indices are formed on the basis of group indices, which are an aggregate of homogeneous, single ergonomic indices: sociopsychological, physiological, psychological and psychophysiological, anthropometric and hygienic. This hierarchic structure includes different levels of integration of ergonomic indices. The study of interchanges from some levels to others constitutes the specific research task of ergonomics.

A distinction is made between two stages (phases) in development of ergonomics and, accordingly, two types of ergonomics, corrective and projective (preventive), which are respectively related to problems of updating existing machines and systems and designing new ones. The approach used in corrective ergonomics implies optimization of activity in each instance, in order for each factor: psychological (when the significance of the anthropometric, physiological and hygienic factors is considered beforehand to be optimal, or else is not considered at all), physiological, hygienic, etc. (with the same stipulations). Then the different data are summed up. It is quite obvious that such a sum of idealized one-dimensional models does not conform with actual conditions of work, where all of the factors are interrelated and interwoven. If the role of scientific basis of complex planning of work were not attributed to ergonomics, such idealization, which is widely accepted in scientific research, would be not only permissible, but logical, since it permits achievement of particularly rigid results and reduction of time spent on studying different aspects of work.

Corrective ergonomics plays a rather important role, uniting specialists in different areas of knowledge to solve important and pressing problems. In corrective ergonomics, efforts are made to bring together, be it often mechanically, facts obtained by different disciplines dealing with labor. Corrective ergonomics has a definite positive influence on planning practice, and it is instrumental in accumulation of different facts about labor.

Formation of projective ergonomics implies not only accumulation of data about human factors, but development of special studies of typical forms and types of human work, creation of methods for analysis and formalization thereof, detection of factors that determine its efficiency. In turn, these objectives make it necessary to analyze factors that affect performance of different types of work, to tabulate the ergonomic typology of different types of work, to develop its own, specific research methods for projective ergonomics.

Planners need a scientifically substantiated tool for planning labor activities, which would permit optimization of MMS. Projective ergonomics, the formation of which permits neutralization of the overtly existing trend of "prescription" ergonomics that harbors the danger of limiting the role of creative analysis in such a complex and important matter as humanization of technology, working and living conditions, is called upon to provide such a tool.

In view of the increasing trend toward technologization of life, specialists in ergonomics are devoting increasing attention to the study of human factors as related to problems of planning, developing and assessing technically complex products for cultural and personal use. However, only the first steps have been taken in this direction.

Ergonomics is playing an ever increasing role in solving the complex problem of rehabilitation of individuals who have become disabled to some extent or other. Such rehabilitation is a system of government, socioeconomic, medical, professional, pedagogic, psychological and other measures directed toward returning the sick and disabled to society and socially useful labor. One of the important directions of ergonomics is the study of the capabilities and distinctions of different categories of disabled people in order to take into consideration the results obtained when planning equipment for public, administrative and residential buildings, as well as different rooms, work places and different industrial products. For the same purpose, ergonomics studies the psychophysiological capabilities and distinctions of the elderly.

With investigation of the MMS as its main object, ergonomics studies some of their specific properties. These properties were named human factors; they constitute the integral characteristics of the relationship between man and machine (technological means), manifested under specific conditions of interaction when the system is in operation, which is related to achievement of concrete goals.

According to this definition of human factors, they cannot be reduced to the characteristics of man, machine (technical means) or environment per se. Obviously, basic knowledge about each of these system components, which is available and obtained in the relevant disciplines, is used to single them out and define them. From the above definition it also follows that the characteristics and properties fixed in the concept of human properties do not constitute individual, isolated features of MMS components, but are its aggregate, systemic qualities. "A new quality [trait], which arises as the product of integration, union of many elements into a single whole, yields something more than the sum of the elements; it reflects certain general cooperative properties of a given set of phenomena, and it represents supraindividual certainty" [19, p 83].

In relation to the properties-traits of MMS components, human factors are secondary traits, which arise as a result of integration, embodiment in one whole of innate traits characterizing the environment, objective traits characterizing the machine (technological means), functional traits, including social ones, characterizing man. Ergonomics is not concerned with all possible "primary" traits of man, machine or environment, but merely with those that are determined by the position and role of man in a MMS, and for expressly this reason they are called human factors. Evidently, the most perfect and efficient models will be those in which the quantity of human properties and traits, set in a functional relationship with his place in the system, with its innate and objective qualities, will be at a maximum. For expressly this reason, to optimize human work and assure the efficiency of the MMS, the competence of individual disciplines dealing with various aspects of work is not sufficient.

Ergonomics must provide the necessary and sufficient nomenclature of functional relations between MMS components, since it is only in this case that the MMS can acquire the status of a system with the specified efficiency and meeting specific criteria. The nomenclature of functional relations must be constructive (and not infinite), and it must meet a number of criteria of rating MMS's, both technical (stability, reliability, resistance to interference) and socioeconomic. Concretely, this means that ergonomics does not simply operate with various sets of base properties, traits and indices (hygienic, physiological psychological, socioeconomic, technological, ecological, etc.) obtained in the relevant disciplines, but transforms them into systemic traits by establishing the necessary number of functional relations between them.

Human factors, construed as integral MMS characteristics of utmost importance, thus constitute a certain superposition of base indices and, accordingly, fixed (or dynamic) functional ties between MMS elements and components. Since the MMS represents a certain functional structure, from the standpoint of ergonomics the human factors emerge as the chief, system-forming elements, or taxonomic units of analysis of the functional structure of the system. Of course, the functional structure of the MMS is characterized not only by human factors, but others as well: organizational, informational, territorial, etc. For this reason, singling out the human factors as units of analysis, i.e., elements of the functional structure of the system, does not, of course, preclude singling out taxonomic units of another type, depending on the objectives of analysis of such systems.

Human factors are not homogeneous. It is a rather complex and special task to single them out and classify them. It is important to mention that human factors themselves emerge as structural elements differing in complexity. When interpreted in precisely this manner, they represent a certain temporary combination of forces capable of a specific achievement.

Such an interpretation of ergonomics and human factors disagrees with the popular view of ergonomics as a set of disciplines dealing with work or a sort of metadiscipline that integrates others. The status of ergonomics is determined by the fact that it operates with data obtained in other sciences, transforms them, developing its own initial conceptions and resources, and pursuing its own goals and objectives, which are related to organization and planning of the conditions and methods of man's work in the system.

As we have already noted, expressly human endeavor serves as the basis for singling out the human factors that must be taken into consideration in determining the functional relations between MMS components. There is equal validity to the fact that the presence of such functional ties is the necessary basis for organizing successful performance by man in the system. This means that the human factors are not given from the start. They are something that is to be sought, something that can be found only on the basis of preliminary analysis of MMS tasks, human functions in the system, the nature and type of man's work.

Such analysis is a mandatory prerequisite in planning MMS's. That it is done with greater or lesser professionalism, on an intuitive or scientific level, empirically, experimentally (on appropriate prototypes, mockups, experimental stands or actual devices) on the basis of practical experience, is another matter. As a result of such preliminary analysis of work, determination is made of the list of human factors, consideration of which is necessary for efficient operation of the MMS. The thoroughness of human factors singled out and, accordingly, the abundance and fullness of potential functional ties between MMS components that could be determined at the stage of planning the system alleviate substantially introduction of these systems, including formulation of occupational screening requirements, personnel training, coordination of external means of work and methods of performing it, etc. A properly determined and designed system of human factors is largely involved in determining MMS planning, providing for greater efficiency of its operation and aiding in successful performance of tasks given to it.

Thus, man's work is the beginning and end of an ergonomic study, ergonomic evaluation and ergonomic planning. The concept of work [activity] thus services also as the theoretical basis for the above interpretation of human factors. For this reason, new conceptual schemes of work are formed in ergonomics, as well as new methods of analyzing it which, in turn, stimulates development of general theory of labor activity. In this respect, the problems of ergonomics overlap those of praxeology, whose task is to study the general laws of any activity and to determine the most general rules of its organization.

On the basis of Marxist teaching on objective activity, its development and forms, there has been an objective spin-off of ergonomic research into the area of theory and methodology of studying working activity. Ergonomic problems can be effectively solved only "if synthesis of social and natural sciences will not be headed on the road of mechanical combination of the data from some disciplines or other into a certain summated system or conglomerate of knowledge and not on the road of 'subordination' thereof, but rather if it bases itself on general theory of working activity" [43, p 63].

Ergonomics solves problems of rational organization of human work in the MMS, purposeful distribution of functions between man and machine, definition of criteria for optimization of MMS with due consideration of the capabilities and distinctions of a working man (group of people), and it develops the typology of such systems. Ergonomic problems include those of defining the methods of evaluating the dynamics of the functional state of working people and optimum parameters of the MMS environment.

Systematization and analysis of publications in journals provide some idea about the content of ergonomic research. The English abstract journal, ERGONOMICS ABSTRACTS classifies all work on ergonomics in the following way (listed in abridged form):

I. Work of a general nature.

II. Man as a component of the system: 1) Perceptive (input) processes (sight, hearing, etc.). 2) Central processes (short- and long-term memory, decision making, attention, etc.). 3) Main motor processes (tracking, motor skills, manual skill, etc.). 4) Characteristics of perceptive-motor activity and factors affecting it. 5) Main physiological processes. 6) Working conditions (static and dynamic loads). 7) Anthropometric and biomechanical data. 8) Main data referable to physiology of sense organs and factors influencing their physiological and biomechanical functions (fatigue, stress, etc.).

III. Planning the means of interaction between man and machine: 1) Visual, auditory, kinesthetic and tactile indicators. 2) Control organs and specialized input devices. 3) Planning of work area. 4) Design of equipment, instruments, mechanisms and machines, special safety gear. 5) Physical environmental factors (lighting, noise, vibration, temperature, atmospheric conditions, etc.).

IV. Planning and organizing systems: 1) Distribution of functions between man and machine. 2) Planning and organizing work (pace, work shifts, etc.). 3) Training. 4) Screening. 5) Motivation and attitude toward work.

V. Methods of research and experimental techniques in ergonomic studies: 1) Methods and instruments for measurements, analysis and evaluation of data. 2) Training program, screening procedures, testing, methods of interrogation, etc. 3) Modeling, including on computers. 4) Statistical data processing and experiment planning, including the use of computers.

The above list shows that there is some superfluousness of information, due to the requirements for data retrieval.

Ergonomics not only studies, but plans purposeful variants of specific types of human work related to the use of new technology. On the basis of the work plan developed in accordance with the main objectives of the

MMS that is being developed, specifications are formulated for the technological means used in the work and, at the same time, for professional screening and training, as well as the training equipment. Not only do exogenous means determine the methods of work, but the external means are also "transformed" in accordance with work methods, as a result of which there is optimization of conditions that are instrumental in manifestation of human work.

Under socialism, ergonomics is involved in developing conditions, tools and processes for work and life that provide for a better solution to a triple problem: increasing the efficiency of work, preserving human health and comprehensively developing the personality. "Even now, one must apparently ... proceed from the idea of secondary, servicing function of machines in working out a technological assignment and, consequently, one must consider first of all the positive traits of man as the effective subject of labor, i.e., that which makes up his advantages over machines, rather than deficiencies. Basically new reserves are disclosed on this route for increasing the efficiency of labor.... In store is the change from solving urgent problems of organization of labor, refinement of existing technology, man's adaptation to already existing technological norms to planning new types of human work on the basis of complex theoretical research on the potential physical, psychological and intellectual capabilities of man, with which ergonomics is already concerned" [43, p 63].

Planning of human work is based on fundamental psychological research and modeling higher mental functions: perception, memory, thinking (graphic and conceptual). These functions are in essence the actual means or psychological tools for work. These means (methods) include experience, knowledge, programs and systems [schemes] of behavior, operator skills that together make up his professional image. On the basis of the actual means of activity, there is formation of permanent and operational graphic-conceptual models which are the basis of the decision making process and control of human activity, which is subject to special formation and training.

Working man, who uses the arsenal of psychological work tools, bases himself on external means that are provided by the designers of machines and systems. The external means of activity include information models rendered on information display devices (screens, panels, mnemonics, indicator instruments or in the form of a document), computer software (when solving problems together with a computer) and other ancillary means of preparing a decision, control organs and communication devices. Under different conditions, the emphasis of planning may be referable to either external or internal [human] means of activity.

Planning of specific types of human work, both in relatively simple wnd extremely complex man-machine complexes, requires the performance of the most diverse studies. Special publications in the field of ergonomics are saturated with experimental anthropometric, physiological and psychological studies of cognitive and executive work. Moreover, ergonomics has left its imprint on the problems, theories and methods of research in the above disciplines. The findings obtained in the sciences dealing with man now perform more than the function of illustration and proof of some theory or hypothesis. They also acquire independent practical significance. Knowledgeable planning of exogenous means of work and formation of methods of performing it require not only theoretical knowledge about the structure of human activity, but of a large number of quantitative data pertaining to accuracy, speed, stability and immediacy [ongoing nature] of performance of different types of activity. Such data can be obtained only on the basis of development of new methods of experimental research and special experimental stands. Their complexity (and cost) are sometimes commensurate with the actual complexity of the technological equipment that operators of modern automated control systems have to deal with.

With this scope of experimental work and their orientation toward the solution of practical problems, there is particularly great importance in methodological studies.

Ergonomics is faced with two classes of methodological problems. The first is related to the fact that ergonomics is a field of interdisciplinary research. For this reason, the most important task is to develop the methodological means of recording and synthesizing results obtained in different fields of knowledge, upon which ergonomics bases itself. One should not conclude from this that ergonomics cannot develop with success until there is a solution, for example, to the age-old problem of correlations between the psychological and physiological elements. In ergonomics, this methodological problem is posed in a rather concrete form, and it acquires the appearance of a problem of compatibility in one experimental study of both various methods and means of interpreting the results of obtained. Even now, some positive experience has been accumulated in psychological studies of various types of objective cognitive activity, with concurrent polyeffector recording of physiological functional structures and systems involved in performance of these types of activity.

Ultimately, data are obtained which permit characterization not only of overall effectiveness of activity, for example, in the mode of detection, data retrieval or informational preparation of a decision, but also the energy expended by the phsyiological functional systems involved in its performance. On the basis of such integration in a single experimental procedure of methods that were developed in different disciplines, in particular, in psychology and physiology, it becomes possible to make more realistic forecasts about the efficiency and possible functional states in the planned types of activity. Analogously, experience is being gained in concurrent study of anthropometric, biomechanical and psychological aspects of executive activity, for example, in the mode of sensorimotor tracking and operation of controls, inclduing those with 2-3 degrees of freedom.

The second class of methodological problems confronting ergonomics could be called intradisciplinary. In each of the disciplines, upon which ergonomics relies and the results of which it uses, there are various methodological approaches, conceptual systems and methodological procedures for studying and describing the same phenomena. These conceptual schemes emerged in their day to solve specific scientific and practical problems, which do not coincide always by far with the problems of ergonomics. But this does not by any means signify that the young scientific discipline must manifest "methodological rigorism" and necessarily expound its own methodological conception, so to speak, in a void, so long as this methodology is original, ergonomic. It is another matter that, when testing the applicability of some previously formed conceptual systems and methodological approaches to ergonomic problems, it becomes necessary to partially revise, enlarge upon and alter them. Work on problems of methodology and methods of research aids in expounding theory of ergonomics and thereby enriches the practice of specific research.

2. Interdisciplinary Relations of Ergonomics

At the present stage of development of ergonomics, the question of correlation between its subject and those of allied disciplines acquires special significance. This is considered important, not only from the standpoint of defining the conceptions of ergonomics as a science and demonstration of the constructive routes of its formation, but from the standpoint of solving practical problems of organizing the relevant scientific research and effective use of its results in various areas of endeavor.

Ergonomics, which deals with complex studies of man under specific conditions of his activity with the use of machines (technological means), is governed by the basic principles of Marxist-Leninist philosophy on social and objectively active essence of man; about the integral and concrete-historical understanding of man; about the essence and content of the labor process as human objective activity, which transforms nature and produces the entire world of human culture; about technology as a system of material, artificially developed means of human activity; about man and his comprehensive development as the highest criterion of the value of scientific, technological and social progress. The theory of integrity of man, which is being expounded in philosophy, constitutes the methodological basis for complex studies of interaction between man and machines, man-machine systems and the environment.

As it studies the patterns of formation of a new society, scientific communism serves as the methodological basis for defining the goals and tasks of ergonomics under socialism. Being directly related to the creation and development of technology, the study and refinement of human labor, ergonomics is governed by the theses of political economy, the discipline dealing with laws that control industry, distribution and exchange of necessities of life in a human society.

Ergonomics interacts with social, natural and engineering sciences. The continuing process of formation of ergonomics takes place in contact with many areas of scientific and practical endeavor, and it enables us to refer to basic sciences in relation to ergonomics, to a set of scientific disciplines that are specially involved in ergonomic research and, finally, to ergonomics proper as an area of scientific and practical endeavor.

The logic of development of ergonomics links it more and more with sociology and, first of all, industrial sociology, which is given the leading role in implementation of a complex approach to the study of labor (nature and content of labor, correlation between various incentives and factors of being satisfied with the work, social aspects of rational organization of labor, etc.). In industrial sociology, an important place is given to the study of "man-technology" systems [40]. Studying the social aspects of work activity and patterns of functioning of groups of workers, industrial sociology is working on a wide range of problems that are the methodological starting point for many ergonomic studies. Sociological studies permit more specific integration of the principle of objective determination of endeavor with the principle of subjective activity. As it applies to work, the source of human activity lies in the correlation between interests, since the individual always performs this activity as a member of some social community, and it is directed toward satisfying the needs and interests of a specific social group, class or society as a whole [47].

Using the results of studies in industrial sociology to study many applied problems, erognomics in turn begins to have an increasing influence on the former. The general tendency in development of sociology, whose task is "not only to describe the present state of social objects, not to limit itself to a general forecast of their future state and preparation of practical recommendations as the 'by-product' of studies, but it must specially elaborate a system of new ways and means that would permit prompt and accurate exertion of influence on the objects of social control as a whole and intensify their development" [20, p 166], is significantly instrumental in strengthening these correlations.

Links with sociology is a mandatory prerequisite, but not the only one, for use by ergonomics of a complex approach to the study of man under specific conditions of activity. Links with social psychology, which deals with the patterns of human behavior and activities determined by the fact that they are in social groups, as well as psychological characteristics of these groups, are important to ergonomics. If these links are overlooked, it usually leads to a situation, in which the researcher becomes incapable of seeing a live man behind the mean statistical data and schemes, with all the wealth of his sociopsychological relations [42]. Studies by social psychology of the cooperative joint activity of group members define its most significant ties with ergonomics. Theory of activity-mediated intragroup relations [35] is of basic importance to ergonomic studies and planning of group (team) work. At the same time, the activity-oriented approach in ergonomics also enriches this theory.

Studies of informal relations of all types in groups are also important to ergonomics: horizontal, vertical and "diagonal" (relations between individuals with different job status, but not under immediate subordination). Of particular interest is the approach that emphasizes the role of business relations (including those of responsible dependence) in the formation and development of a work team. The study and planning of specific forms of labor activity imply consideration of sociopsychological factors, which have a direct influence on the nature and results of activity. In this respect, two main directions of studies of the sociopsychological climate, which refers to the prevailing and relatively stable spiritual atmosphere, mental set of the group manifested by both people's attitude toward one another and the group's atitude toward a common cause appear to be the most important.

Sociopsychological studies of attitude toward work and, first of all, satisfaction with work, involvement of the individual in the work, occupational and social adjustment, etc., also have a direct or indirect bearing on the range of problems of ergonomic research.

Ergonomics needs to establish firm ties with industrial economics, the subject of which is labor in its historically defined form, social and national economic organization of labor.

At the present time, there is a tendency toward interpenetration of psychology and economic science due to the need for objective development of productive forces, change in nature of labor in the course of the scientific and technological revolution, need to improve personnel screening and training, increasing significance of rationalization and organization of labor for effective use of the "human factor," etc. [45]. Approximation of ergonomics and economics occurs under the influence of the same processes. Determination of the socioeconomic effectiveness of new technology, which has become a pressing problem of economic science, is an area where the interests of economics and ergonomics overlap. Without the back-up of ergonomic knowledge, it would hardly be possible to obtain a productive solution to this problem. "The possibilities of increasing labor productivity and, consequently, economic effectiveness are found in the newest technology as such. But implementation thereof does not occur automatically; rather it does when technology is creatively used by man in the production process. The extent to which the potential economic effect is realized depends on how technology influences man, his living conditions in society and working conditions in industry in the course of using this technology" [25, p 12]. In turn, the possibilities of continued development of ergonomics and, particularly, of using its findings in different sectors of the national economy will depend appreciably on the work on the range of problems related to determination of the socioeconomic effectiveness of new technology.

As we have already mentioned, the status of ergonomics is determined by the fact that it operates with data obtained in other disciplines and transforms them, developing its own base conceptions and means. Development of the general concept of MMS and appropriate language for describing it as an integral whole, coordinating descriptions of this system in the languages of different disciplines is considered to be one of the important tasks for ergonomics.

Ergonomics is primarily concerned with the functional structure of the MMS, which is determined by the place and role of man in the system, internal relations of this system and interaction with the environment, whereas industrial psychology, physiology and hygiene concentrate their scientific interests on the study and modeling of different components of this system and their interaction with other of its elements. "The complexity of studying man engaged in production is related to solving two parallel and interrelated problems in each of the disciplines forming a complex: 1) studies of each element of such a system, distinctions and patterns existing within this element; 2) studies of correlations between elements, of existing relations and feedback" [24, p 27].

Ergonomics cannot fail to be concerned with the study of individual elements of the system, just like industrial psychology, physiology and hygiene cannot overlook the relations between the elements of the system they study and other components, and the system as a whole. Consequently, it is important to study the relationships existing within this complex system, not only from the standpoint of ergonomics, but of the disciplines, at the junction of which it emerged. Moreover, it is only by studying these relations that it is possible, for example, to solve the theoretical and practical problems put to industrial physiology.

The main objective of industrial physiology is to study the patterns of physiological processes and distinctions of their regulation in the course of work activity, i.e., demonstration of the distinctions characterizing the functioning of physiological systems and the entire body, as related to the existing relations between the above elements in the system [24].

Ergonomics does not rule out or replace research that is conducted in the field of industrial physiology, hygiene and psychology, it is based on them and synthesizes their achievements. Ergonomics uses the results and stimulates definition of optimum characteristics of the work process, which permit achievement of high efficiency of labor, studies of changes in functional state of the human body under the influence of his work, which are conducted within the framework of industrial physiology.

Ergonomics is guided by the data in industrial hygiene, which studies the effects on the human body of work processes and factors in the industrial environment surrounding man, and develops hygienic standards and measures to provide good working conditions and prevent occupational diseases.

Ergonomics could not exist and develop without the support of the entire set of studies in industrial hygiene, since the goal of the latter is to provide scientific substantiation for the biological optimum, to which the environment must conform in order to assure normal development, good health, high efficiency and longevity of man [18]. The internal logic of research dealing with determination of optimum parameters of microclimate, lighting and other factors of the industrial environment demonstrates the most fully the vectors of the required relations between industrial hygiene and other disciplines, including ergonomics. By studying the effects of factors in the industrial environment of man on the quality of his professional activity, ergonomics gives impetus to work on specific problems of industrial hygiene. Moreover, ergonomics makes a substantial contribution to setting standards, developing ways and means of preventing the deleterious effects on man of various factors of the industrial environment.

It is very important to ergonomics to establish close ties with psycho-hygiene, which deals with scientific bases of ameliorative measures pertaining to mental health of people in order to prevent diseases. The link between ergonomics and psychoneurology, which permits disclosure of the genesis and pathophysiological mechanisms of neurotic states that occur, in some cases, among workers in the course of their work and, in particular, in stress situations, is equally important.

Ergonomics is called upon to supply the missing link in interdisciplinary studies of working man. Ergonomic research, which is instrumental in developing a complex approach to the study of work activity, causes development of certain "junctions" between different disciplines that deal with working man. Problems are solved that have been posed by the very logic of development of these disciplines and attributable to changes in the nature of the practical tasks put to them. In this regard, we can mention that formation of a discipline, related to industrial psychology, such as industrial psychophysiology [41], is becoming a pressing need.

Complex studies of working conditions, hygienic evaluation of new technological processes and equipment, psychophysiological studies of certain forms of labor, further development of scientifically substantiated measures to control monotony, hypodynamia and hypokinesia--all this permits fuller use of the achievements of scientific and technological progress to improve working conditions. "In solving these problems, industrial hygienists and physiologists must devote more attention to cooperation with technological and planning institutes for evaluation of new processes and equipment at the planning stage and alteration thereof in accordance with hygienic and ergonomic requirements" [14, p 2].

The complex approach in disciplines that deal with working man is implemented not only on the level of interdisciplinary interaction, but within the framework of different disciplines in the course of studying various objects using one or several methods of a specific discipline. "As a rule, in complex studies of working conditions, a hygienic evaluation is made of the technological processes proper, equipment, instruments, raw material, by-products and intermediate products, as well as the final product, sanitary engineering installations, general and personal safety equipment, architecture, construction and planning of industrial buildings and rooms, natural and artificial light in them, as well as physiological and hygienic evaluation of organization of labor and individual labor operations" [17, p 141].

Ergonomics could not develop without a link with human anatomy, the discipline that deals with the shape and structure of different organs and the body as a whole. Functional anatomy, which defines the correlations between structural distinctions of human organs and systems, on the one hand, and the nature of their functions, on the other, is one of the scientific disciplines, on the boundary of which ergonomics emerged. Studies of correlations and mutual determination of morphological biochemical and psychological characteristics of man are of particular interest to ergonomics. Ergonomics makes use of and further develops the aggregate of methodological procedures inherent in anthropometric studies, which are used to measure and describe the human body as a whole and different parts thereof, as well as to determine the quantitative characteristics of their variability.

The complex approach to the study and planning of human activity causes close and multilevel relations between ergonomics and psychology [33], in the subject of which activity is not included as a special "part" or "element," but as a special function of the individual's [subject's] belief in objective reality and its transformation into a form of subjectivity [22]. It is not only that the psychological factor is an element of human factors in technology. Ergonomics is linked with many branches of psychology: industrial psychology and engineering psychology, aviation and space psychology, social psychology and psychology of the personality [individual], military and pedagogic psychology. Ergonomics makes full use of the methods established and formed in psychology for studying cognitive and executive activity and, in some cases, it develops and creates new ones.

Being related to industrial sociology, occupational pedagogics, industrial physiology and hygiene, functional anatomy and esthetics of engineering, industrial psychology has laid a broad scientific foundation for the emergence of ergonomics [36]. This was significantly aided by the process of solving a dual problem, which is considered pressing for the present stage of industrial psychology: 1) analysis and evaluation of relevant conceptions of disciplines dealing with labor for the purposes of industrial psychology and 2) concurrent determination of the significance of psychological conceptions to disciplines dealing with labor [48].

Establishment of multifaceted relations between industrial psychology and other scientific disciplines, including ergonomics, is largely determined by the synthetic nature of the psychological factor in the labor process, which is reflected, in particular, in psychological analysis of activity. At all stages of development of industrial psychology, it has concentrated on the psychological factors, quantitative characteristics of work activity, which acquired special scientific and practical significance in our times. Development of the psychological conception of quality of labor is one of the most important problems of industrial psychology. Creation thereof will stimulate further work on many problems of industrial psychology. At the same time, its ties with allied scientific disciplines and, first of all, with ergonomics, for which the problem of quality of labor is among the most important, will be strengthened and developed.

Engineering psychology is a branch of psychology that is closest to ergonomics with regard to conditions under which it was conceived and, mainly, its tasks and methods. In recent times, the idea has been voiced, not without justification, that engineering psychology, being historically related to industrial psychology, is forming nevertheless as an independent branch of psychology characterized by profoundly specific experimental methods, theoretical conceptions and approaches [27]. This is attributable, first of all, to the specifics of the subject of study, in the capacity of which the performance of an ASU [automated control system] operator was singled out, already at the early stages of development of engineering psychology, with physical models of control and substitutes for real controlled systems [10].

Being a branch of psychology, engineering psychology examines only some specific aspects of man-machine interaction, and in this respect it also emerges as one of the sections of ergonomics, the task of which includes complex studies of different aspects of interaction between man and machine, the MMS and environment. "Engineering psychology could actually be viewed as one of the disciplines that contributes to a broader area of research on human factors" [50, p 699].

Engineering psychology directly preceded the appearance of ergonomics in our country. It also strived to keep a complex record of human factors, and it outgrew quite rapidly the confines of actual psychological analysis of work. At the start of its development, engineering psychology solved the most acute and pressing problems pertaining to organization of the work of MMS operators with automation devices. They included, first of all, problems of sensorimotor tracking, detection and discrimination of useful signals in the presence of noise on cathode-ray tubes, upgrading of mnemonics (controls), etc. For this reason, the problems of engineering psychology began to be formulated in more general terms: development of principles of planning information models, studies of processes of information retrieval, information preparation and decision making; finally they became even broader: organization of informational interaction between man and machine. Of course, there was also transformation of research subject matter at each stage of development of engineering psychology. Responding to practical demands, engineering psychology proliferated into an ever increasing range of tasks and problems, for the solution of which the competence of psychologists was no longer sufficient. Anthropologists, bioengineers, physiologists, hygienists, designers and other specialists began to be called upon to join with teams that had to solve problems of engineering psychology, and this resulted in development of the appropriate ways and means of complex research. Expansion of the subject matter of research and planning in engineering psychology led to the natural transformation of the engineering psychology service in industry into ergonomic, although the name remained the same for some time. Appeals for "psychologization" were the distinctive reaction to this process of Soviet engineering psychology. In essence, this meant awareness of the need for stricter definition and narrowing of the area of research in engineering psychology for the purpose of its effective development as a branch of psychology, a leading section of psychology of man's labor.

Concurrently, there was a transformation in problems handled by engineering psychology, in the true sense of the word. It was and continues to be induced by the rather rapid change in automation hardware: appearance of newer generations of computers, information display devices and controls. Refinement of these work tools leads to a growth in scope of MMS's, which become hierarchic, and there is a considerably larger volume of information in computer memory, greater accessibility thereof to operators, possibility of requesting the same information in different forms--textual, symbolic, graphic, etc., drastic improvement in quality of displaying information, broader possibilities for utilizing color and coding of information. The possibility of adjusting display systems to users no longer appears fantastic. In the near future, the user will be able to select not only the brightness, contrast, angular dimensions of an image and elements thereof that are convenient for him, but also the method of writing letters, digits, etc.

All this results in the fact that the subject matter of engineering psychology is shifting more and more to the area of research on decision making, organizing dialog interaction with computers. Operators are changing into users of computers and other automatic equipment. At the same time, refinement of the latter is putting some qualitatively new tasks to engineering psychologists. The volume of data stored in computer memory is so great that they cannot all be displayed simultaneously, and when displayed successively they are difficult to visualize. Nor does a general information model save the day, since generalization of information can be made on many bases. In other words, it is not so much the information model transferred to information display devices as the information model stored in the computer's memory that becomes the object of operator (user) activity; not infrequently, the latter is called the information block, the aggregate of data bank bases. When referring to these data bank bases, the operator must himself form the dynamic information model, which requires utterly different training, knowledge about the aggregate of data bank bases, ability to interpret them, knowledge of the possible levels of data processing and different bases for classification thereof. The most difficult task is to construct a logical order of data bank bases on the basis of complex, heterogeneous and diverse information models, transfer thereof to display equipment, followed be evaluation, correction, modification and decision making. This is only one example of the new range of problems of engineering psychology, which requires that it develop intensively in even closer contact with general and experimental psychology. Of course, as ergonomics prepares the requirements for consideration of human factors in engineering, it is governed by and uses the results of both prior and the most recent research in engineering psychology. This applies to the same extent to other disciplines dealing with labor and work activity.

It is premature to maintain today that all problems of correlation between engineering psychology and erognomics have been resolved. Some difficulties still arise, and they are related primarily to the fact that the formation of engineering psychology and ergonomics is a continuing process. The subject of both disciplines is being defined and, in some cases, even re-emphasized. Nevertheless, some clarity has been brought in the main and substantial point that characterizes the unity and difference between these two areas. Whenever differences are not demonstrated between ergonomics and engineering psychology and they are equated, fruitless debates occur, the cause of which is not a difference in views, but terminological misunderstandings [52].

At the present time, the development of psychological science is stimulated, in many respects, by the tasks of ergonomics, which introduces into its context some forms of work, new means of performing it and of studying it. In the near future, we should expect further deepening and broadening of the ties between ergonomics and psychology.

When planning man's activity in control systems, usually problems of occupational screening, education and training are resolved at the same time. Combining in an integral system the planning of work activity, professional screening, education and training makes it possible to perform each of these tasks on a qualitatively different level than is done in other cases. This dynamic system is called upon to solve problems, not only of optimum adaptation of machines to man, but active development of human skills to conform with the requirements made of man by technological progress and the capabilities that are disclosed to him with the development of technology.

Ergonomics, along with pedagogics and pedagogic psychology, is called upon to aid in the process of refinement of polytechnical education in the schools, in order to provide a certain vocational guidance and appropriate training of young generations for work with the new technology that is being planned and developed. In the course of polytechnical education one can start acquainting students with ergonomics as an element of general, industrial and labor culture.

One of the most important problems is to establish the relative significance of psychophysiological functions activated by professional work to development of polytechnical sets and skills. By synthesizing the achievements referable to a number of disciplines dealing with work activity and engineering, ergonomics can aid in establishing appropriate intersubject relations and better organization of the teaching process itself. For this reason, there is some validity to statements that it is high time to create pedagogic ergonomics. The problem of taking into consideration the content and methods of teaching students (future blue-collar workers, engineers, etc.) in secondary schools when preparing the ergonomic specifications for machines, work places and the industrial environment.

Under socialism, scientific organization of labor and ergonomics have the same goals: to aid in increasing labor productivity, preserving health and development of the personality. There are many common directions of research, which are related primarily to the study and planning of work processes, refinement of organization and servicing of work places-improvement of working conditions. At the same time, scientific organization of labor and ergonomics are different levels of study and planning of work processes, between which there are certain correlations and transitions from one level to another. At each of these levels, their own inherent laws are established, and this is reflected in a certain theory, system of concepts and categories [12, 23, 32, 34].

Ergonomics and scientific organization of labor work with different units of analysis of work activity, for the definition of which the same terms are sometimes used. Ergonomics has adopted the scheme of units [entities] of analysis of work that is being developed in psychology: specific activity, action and operation [22]. Activity is directed by motivation, behind which there is always the subject's need.

Motivation not only prompts activity and creates its direction but, what is very important, it imparts to activity (and all processes that implement it) a certain personal meaning (one could also say subjective value). Operations, procedures, actions and movements are the units for analysis of the work process in scientific organization of labor. "The operation is the main element of the work process. It is performed by one or several workers at the same work place on the same object of labor. A work procedure combines several work actions by man's working organs, which are performed without interruption to perform some elements of the same operation. Work action is the aggregate of working movements of the fingers, hands, legs, as well as body of a worker, which are performed without interruption. Work movement is the single displacement of fingers, hands, legs, as well as body in the labor process. Work movement can be broken down into micromovements" [37, p 9].

A comparison of units of analysis of work activity used in ergonomics and scientific organization of labor enables us to maintain that we are dealing with studies of the same object that differ in content. In the former case, attention is focused mainly on demonstration of internal patterns of activity, whereas in the latter case there is predominant consideration of external manifestations of the same activity. This difference is also reflected in the investigative methods used, although some of the methods are the same in ergonomics and scientific organization of labor. Organization of labor under modern industrial conditions, characterized by complex mechanization and automation of production processes, has raised a number of new problems, the effective solution of which is possible only by means of scientific synthesis of data pertaining to work activity of man. The integration of results of studies, which were obtained in different scientific disciplines, which is made by NOT [scientific organization of labor], must be enlarged by the results of such synthesis, which is made in the course of interdisciplinary studies. Ergononomics is one of the directions in which such synthesis is made.

Ergonomics and NOT are two independent but organically interrelated areas of scientific and practical endeavor. Ergonomics is making an increasing contribution to the cause of socialist NOT. The process of continued interaction and reciprocal development of ergonomics and NOT is demonstrable in three main directions.

The first direction is related to work on theoretical problems, primarily problems of planning group and individual work processes. One of the first and foremost problems is socioeconomic effectiveness of introduction of NOT and results of ergonomic studies in the national economy.

The second direction of application of joint efforts of specialists in ergonomics and NOT is establishing the standards and requirements of NOT and ergonomics. The work being done in this direction must be expanded significantly and given scientific substantiation. This direction is closely linked with the first one, since the effectiveness of development of these standards and requirements depends largely on the study of theoretical problems.

Finally, the third direction is related to the direct use in industry of the achievements of ergonomics. Experience has shown that the maximum effect is obtained when measures in the field of ergonomics are included as elements of NOT plans. Ergonomists, together with specialists in NOT, should become more actively involved in processes of technological re-equipment and remodeling of existing enterprises. "An important distinction of modern remodeling is that, in addition to technical re-equipment which provides for an increase in production and decrease in operating expenses, it is solving to an ever increasing extent socio-economic problems, i.e., improvement of working conditions, elimination of heterogeneity of labor of workers in different occupations, overcoming the substantial differences between mental and physical labor, raising the physical standard of living of working people and protection of the environment" [39, p 22].

Ergonomics is playing an increasing role in providing safe working conditions [7]. Labor safety regulations refer to a system of legislative documents and corresponding socioeconomic, engineering, hygienic and organizational measures that assure safety, safeguard the health and fitness of man in the process of working.

Consideration of the requirements of ergonomics is a mandatory prerequisite for creating convenient, reliable and safe technology. Basing itself on work in the area of labor safety, ergonomics supplements and develops it in some respect. It is becoming generally recognized that the number of accidents ultimately due to dangerous actions is considerably greater than the number of accidents due to dangerous conditions. In this regard, it is noted that ergonomics opens up new opportunities to define the latent causes of unsafe actions that could lead to accidents.

The problem of criteria of assessing the difficulty and intensity of labor, which can be solved only by using a systems approach and on the basis of the advances in industrial hygiene, physiology and psychology, industrial economics and other disciplines, reflects the most the need for organic correlation between labor safety and ergonomics. The ergonomic approach is necessary for the study of difficulty and intensity of labor, which are manifested by the functional parameters of the body formed under the influence of physical, mental or emotional load and factors of the industrial environment.

Use of the achievements of ergonomics permits more effective solutions to current problems of labor safety. As far back as the 1930's, there was discussion of the matter that requirements pertaining to improvement of health-related and safety conditions of work must become an organic element of the process of developing technology, rather than attached to it as something extraneous and independent. Under modern conditions, such formulation of the question has become a real problem. "Our goal," stressed L. I. Brezhnev in a speech at the 16th Congress of USSR Trade Unions, "can be formulated as follows: from labor safety techniques [practices] to safe techniques. We are on this route and will advance persistently on it" [4, p 187]. On this route, close relations are established between labor safety and ergonomics, which is one of the important areas of work on scientific and methodological problems of creating safe techniques [equipment].

Many problems and practical tasks are worked on by ergonomics in close collaboration with design, which makes it possible to implement the most fully its principles and requirements. Ergonomics is viewed as the natural scientific basis of design [30]. In turn, design enriches the range of ergonomic problems studied by means of including it in a broader context of development of culture [31]. On the practical level, consideration of human factors is an inalienable part of the entire process of aesthetic design of industrial products and corresponding transformation of the industrial and objective-spatial environment. In pricniple, design cannot exist and develop apart from ergonomics.

Ergonomics is closely related to engineering and mathematical sciences: cybernetics, systems analysis, general theory of systems and study of operations, as well as other disciplines and directions of modern scientific research.

Ergonomics solves a number of problems posed in systems analysis: evaluation of reliability, accuracy and stability of work, effect of mental tension, fatigue, emotional factors and distinctions of the neuropsychological organization of an operator on efficiency of his performance in the MMS, adaptive and creative capabilities of man. In practice, the correlations between ergonomics and systems analysis refer to the problem of organizing comprehensive and professional consideration of human factors at different stages of developing and operating systems. Consideration of human factors is a mandatory component of development of structural and functional schemes of both the system as a whole and its individual elements.

Ergonomics is related in some way or other to all sciences the subject of study of which is man as the subject of labor, cognition and communication. In solving practical problems, ergonomics must base itself on the entire system of knowledge about man. As the formation of ergonomics progresses, it is exerting an increasing influence on development of this system of knowledge. "Among the new humanitarian disciplines of utmost importance to general theory of the science about man, we should mention ergonomics, which could be defined as a special science dealing with the labor activity of man" [5, p 13].

The above analysis is indicative of the abundance of interdisciplinary relations between ergonomics and social, natural and engineering sciences, of course, primarily to those aspects that are closest to work activity. As we know, interdisciplinary ties are dual in nature. Not only is ergonomics subject to the influence of sciences related to it, it has already begun to exert an influence on them in the area of theory, methods and practice. At the present time, most obvious is the effect of ergonomics on the last two areas, since applied problems continue to be prominent in ergonomics. Development of complex [cooperative] research leads to a certain change in disciplines involved in a given study [38]. This change is not something artificially imposed on sciences dealing with labor exogenously; it is a logical stage of their development [24]. Ergonomics emerges as a distinctive catalyst of this process.

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CHAPTER III. PRINCIPLES AND METHODS OF ERGONOMICS

The methodology for complex study of man under specific conditions of activity with the use of machines (technological means), including the methodology of ergonomics, is developed on the basis of the philosophy of dialectical materialism, which conforms with the spirit and trends of development of modern scientific knowledge. One can distinguish three types of methodological means in ergonomics corresponding to the three levels of methodological analysis singled out in the literature dealing with philosophy [77]: 1) methodological means of a general philosophical nature; 2) general scientific methodological means; 3) special scientific means.

1. Methodological Means of Ergonomics

Methodological means refers to some knowledge or other, but considered in a special role or function: the function of principle, method, procedure, manner of obtaining new knowledge. In research practice, methodological means do not emerge in their "pure" form; rather, they are organically blended, included in the relevent ergonomic conceptions. The ergonomic methodological means can be interpreted by analogy with what is defined in psychology as general principles of studying mental phenomena, particularly since they are part of the methodological arsenal of ergonomics, and this applies first of all to the principle of unity of consciousness and activity adopted in Soviet psychology. In ergonomic knowledge, the share of the philosophical ["world outlook"] component is rather large, by virtue of the direct orientation toward man and the industrial-practical orientation of ergonomic studies (even if emphasis is not laid on this component in some specific instance). Ultimately, any change in the work process, working conditions, tools and products has certain socioeconomic goals; in modern society it always serves specific class interests, which are different for socialist and capitalistic methods of production.

The philosophical component of ergonomics is reflected the most fully in the area of goals of this discipline, in studies of the history of inception of the subject of ergonomics and its interpretation of the central category, the category of object-oriented activity.

We have already indicated that the general goal of ergonomics is formulated as the unity of three aspects of research and planning: to increase the efficiency of activity and, accordingly, operation of man-machine systems, safeguard health and develop the personality of people involved in the work process. This conception is based on Marxist-Leninist interpretation of the role of labor in a fully developed socialist society, under conditions where labor is changing from a means of sustaining life to a first and foremost necessity, the main prerequisite for development of man's skills and creativity.

Acceptance of the thesis of threefold nature of the general purpose of ergonomics makes it possible to avoid both a narrow-minded practicism and rift between ergonomic research and the concrete tasks of developing socialist industry. This specifies the unity of ergonomic studies, their systemic nature. Of course, there may be prevalence of a given aspect in a concrete study, this is permissible and virtually inevitable. However, the general and single goal is reached through the aggregate and mutual complementarity of these aspects.

The next basic theoretical thesis of ergonomics, which is organically linked with the one just discussed and which serves an equally important philosophical function, is the indication that the "man-machine" relation is primarily a "subject of labor-tool of labor" relation. It is not man who is viewed as a simple element contained in a technological system, but the machine that is viewed as a means included in man's activity [42].

Of immediate significance to ergonomics as a discipline that is directed toward the study and planning of work activity is analysis of the category of object-oriented activity, distinction of conceptual schemes in which this category is used and studied by various scientific disciplines and, first of all, psychology [39]. These conceptual schemes, which define the ergonomic aspect of conceptions of activity, serve a methodological function in relation to concrete ergonomic studies. This function consists of formulation of general philosophical sets through the methodological means of ergonomics of both the general scientific and special scientific type. We must mention the philosophical nature of the theoretical theses of ergonomics that are related to the study of the emergence of the subject of this scientific discipline. They include, first of all, the thesis that appearance of ergonomics is attributable to radical changes in the work process proper, which are related to the scientific and technological revolution, as well as the thesis of three stages in determination of the nature of the relationship between the human and machine components when solving the corresponding scientific and industrial problems [3].

At the first stage, this link was interpreted as man's adjustment to a machine, at the second as the machine's adjustment to man (his psychological, physiological, anthropometric, etc., characteristics). Finally, the third stage is characterized by broader interpretation of the "human factor," as a factor that forms (makes up) the "man-machine" system itself. The distinction of the stages and definition of the specifics of the latter also serve as justification of the general goals of ergonomics, which are interpreted in the conceptions of its subject. The research scheme is broken down into details, from a brief indication of two "man-machine" components to a total "man-group of people-machine-object of labor-industrial environment" system. But the important aspects include more than this breakdown and expansion of number of MMS components that are included in the area of ergonomic research. Also important is the start of overcoming the adaptation-homeostatic approach to the problem of interaction between man and machine in two variants thereof: mechanocentric and anthropocentirc.

The methodological content of the theoretical theses of ergonomics that were formed in the course of processing of general scientific conceptions as they apply to its subject consists of both a special type of vision of the objects of study and planning and combined specification of the object and means of studying it, i.e., construction of a systems strategy of ergonomic research. "General scientific" refers to the concepts and conceptions that are not rigidly related to a given area of scientific knowledge, but at the same time do not have the status of philosophical categories.

The concepts of the systems approach in the broad sense--as one of the leading current general scientific trends--determine many of the initial sets and theoretical theses of ergonomics. They include the following: integral consideration of man-machine systems, dynamic-systemic view of their structure, inclusion of man's work in the subject of scientific examination, tendency toward scientific synthesis of various aspects of research, striving to demonstrate the possible consequences of man's activity. For example, the typical ergonomic interpretation of the complex and integral nature of MMS's includes a new aspect for technology: the influence of the human factor. For this reason, there is an overt tendency toward the use of systemic [systems analysis] methods, i.e., a definite turn toward systemic orientation [41, 42, 55].

Use of the principles of the systemic approach permits different formulation of many research problems. This can be seen particularly well on the example of how the orientation of research on human actions is changing. While the early studies of work activity were characterized by interpretation thereof as a process and the main tasks were to single out and define the stages of this process, within the framework of systemic orientation the scheme of the process is no longer the initial and basic factor. Now, the structure of activity is in the center of attention, and this implies a different interpretation of action itself as a multicomponent formation, each of the components of which has its own functions within the same action (i.e., the action construed as a system). This requires consideration of various systems of action, distinction of levels thereof, etc. [3].

As we see, in describing the substance of the reorientation that has occurred in ergonomics, we actually have to operate with the entire basic "paradigm" of the systemic conception of objects (concepts of structure, element, functions, levels, etc.).

The important theses of ergonomics that characterize its use of general scientific conceptions is that one can arbitrarily give the name of "organismic" to the conception of activity, its likening to a functional organ [element]. This interpretation was first expounded by N. A. Bernshteyn in relation to a motor act [10].

Also of methodological significance are several theoretical theses, expounded either directly in ergonomics or in allied scientific disciplines, which have become an organic element of ergonomics. They include: differentiation between corrective and projective ergonomics, disclosure of the content of the concept of the human factor in engineering; formulation of the problem of complex study and planning of exogenous ways and means of activity; hypothesis of hierarchic organization of operator activity with distinction of systemic and dynamic [operational]-psychological levles; definition of general psychological schemes of activity with introduction of functional units [blocks] as special elements; development of methods of microstructural and microgenetic analysis; hypothesis of dynamic [operational] image; conception of "inclusion" [or switching on]; structural-heuristic approach to the study of information processes, including decision making procedures; mathematical theory of construction of functional structures of man-machine systems, and a number of other theses of "systems analytical" ergonomics.

2. General Description of Ergonomic Research and Research Methods

The systemic [systems analysis] approach is the methodological foundation of ergonomics. On its basis, it is also possible to use in ergonomic research the methods of various sciences, on the boundary of which qualitatively new problems of research on MMS arise and are solved. There is some transformation of the methods used, which leads to the development of new research procedures.

In ergonomics, research methods are used that were formed in sociology, industrial psychology, physiology and hygiene, functional anatomy, cybernetics, systems analysis, etc. The main problem is to coordinate various procedures to solve a given ergonomic problem and synthesize the results obtained with them.

There are specific features in the ergonomic approach to the study and optimization of activity. With regard to methods, this is expressed in the following basic theses: In the first place, the orientation of ergonomics toward planning activity and its components requires the use not only of experimental but a priori planning methods. In the second place, the use of generalized indicators of activity, tension and convenience [comfort] of work in ergonomics implies the use of procedures for obtaining integral criteria on the basis of a system of special indices. In the third place, an ergonomic study or evaluation must always be systemic, and this is feasible only by the concurrent use of various methods reflecting correlations between components and the main properties of the MMS.

A certain strategy for the choice of methods to solve specific ergonomic problems emerges from the above method-related distinctions.

The research methods of ergonomics can be arbitrarily divided into two groups: analytical (or descriptive) and experimental. In m st studies they are closely interwoven and used concurrently, supplementing and enriching one another.

Virtually any ergonomic problem arises as a result of reformulation of actual tasks. For this reason, each practical tasks put to ergonomics must be first analyzed from the standpoint of demonstration of the specifics of the influence of the human factor under specified conditions. A mandatory prerequisite for the professional work of a specialist in the field of ergonomics is the ability to competently analyze industrial activity (labor productivity, progressive knowhow, working conditions, flaws, personnel turnover, typical erroneous actions of working people, traumatism, etc.).

Any ergonomic study ·ust start with analysis of man's performance and function of the MMS. Its objective is to define man's place in solving problems for which the system studied is intended, general psychophysiological description of man's performance in this system, demonstration of the structure of human factors that affect the efficiency of the system as a whole and its parts.

The purpose of such analysis can vary, depending on the specific problem involved. If one has to conduct experimental studies, analysis is needed chiefly to choose an equivalent model of activity or separate typical actions, as well as to define the specific objectives of the experiment. If one needs to make an expert evaluation of the MMS, the purpose of analysis will be to demonstrate the system's components, according to which the ergonomic evaluation must be made. When elaborating the criteria and methods for occupational screening, analysis will be directed toward detection of personality traits that have a substantial influence on performance quality.

Refinement of machine (technical means) design in order to have it take the utmost consideration of the capabilities and distinctions of working man requires, in the first place, exact knowledge about the causes for dissatisfaction with the existing design from the ergonomic point of view; in the second place, it requires a clear idea about the direction in which it should be altered. Answers to these questions can be obtained provided the flaws in organization of interaction between man and machine are detected in the course of preliminary analysis and requirements are defined with regard to technological means and psychophysiological traits of man needed for a given form of work. In the ideal case, answers to basic ergonomic questions of refining an existing technological means and planning a new one should be the result of the analytical stage.

At the analytical stage of ergonomic research, many modern methods of design analysis, which have been well summarized by the English scientist J. K. Jones [26], are found to be useful. Most of them are the result of "spontaneous" psychological analysis (made by engineers or project administrators) of the work of the most talented designers and entire groups which have made outstanding achievements in developing modern technological equipment [means].

Preliminary functional and structural analysis of activity serves to substantiate the goal to which subsequent ergonomic research is directed. Not infrequently, reference to the prevailing opinion about the significance of a specific problem leads to setting false goals that are not warranted by the actual state of affairs. The turn to the experimental level of analysis is fruitful only when the foundation for the experiment has been prepared by a detailed description of the entire set of factors having a direct or indirect bearing on the ergonomic problem under study.

Setting up an experiment implies testing the validity of an expounded hypothesis or system of hypotheses, which reflect in ergonomics certain conceptions of the nature of relation and interaction of a certain group of factors in each individual instance. Hypotheses should be expounded and substantiated in the course of preliminary analyiss of the problem.

The problems formulated in the course of preliminary analysis are solved in the course of an experimental study. There are diverse types of experimental situations and concrete procedures used in ergonomic practice. The concrete content of some of them will be discussed in detail below. It should be stressed that ergonomic experimentation has a number of features that distinguishes it substantially from studies on the analytical level and traditional laboratory experiments.

First of all, the use of the experimental method is directed toward demonstration of the distinctions of organization of interaction between man and machine that are not directly demonstrable through analysis. Under ordinary industrial conditions, rather low demands are often made of man, and he can readily compensate for the existing flaws of a technical device. In this regard, an important procedure is to complicate the work (posing additional problems, simulation of an accident situation, etc.) as an effective means of demonstrating the advantages of one of several variants of the technological means in comparative studies [27]. Performance of a second (or additional) task concurrently with the main work subject to evaluation is used to record the spare time, which refers to the extra time (over and above the required minimum) that the operator may have to prevent deviations of the controlled parameter beyond a permissible range [45]. In turn, the amount of spare time, which changes in accordance with the level of mobilization of the (human) operator, serves as one of the prognostic indicators, on the basis of which one predicts the degree of complexity of work with which the reliability of performance of the operator diminishes drastically [66].

When organizing experimental ergonomic studies, one must take into consideration that the presence of the experimenter, his set and expectations influence the results of the subjects' performance. It is not by chance that the problem of "ecological validity" of laboratory research (possibility of projecting laboratory results to "real life" situations), which was originally formulated in the field of sociopsychological research, also became the object of the closest scrutiny of ergonomics.

It is impossible to directly extrapolate data obtained in the laboratory to real situations because, in the former case, the subjects are acting under the influence of specific motivation, which loses its force the moment the subject leaves the laboratory. For example, an individual agrees to participate in an experiment in the hope of receiving a competent evaluation of his skills, but this motivation is not necessarily important to his professional work. Other motivations that prompt and control the performance of subjects in a laboratory experiment may be the desire to help science or simply to be rewarded. Of course, these motivations are not exclusively specific to laboratory test situations, but one cannot overlook the fact that similar activity in the laboratory and "real life" situations may be determined by different motives. Since the nature of motivation is the decisive factor in regulating performance, generalization of the results of laboratory studies without consideration of the specifics of the motivation factor often leads to misunderstandings. For example, use of feedback for evaluation purposes without reinforcement by tangible incentives did not yield the expected effect under actual industrial conditions (on the Pulsar program implemented at one of the plants in L'vov), although laboratory tests demonstrated that this factor had a significant influence on efficiency of work. Evidently, feedback for evaluation purposes had a regulatory effect on subject performance in the laboratory when there was a strong enough motivation background formed in the experiment. Evaluating feedback per se, without appropriate motivation, has no appreciable effect. Extrapolation of the results of such experiments to real industrial situations can be made only after proper and comprehensive interpretation of the data obtained, including consideration of the specifics of subjects' motivation.

The restrictions that laboratory conditions impose are the reason for the ever increasing interest of researchers in conducting experiments directly in industry. However, even these experiments are not without flaws. Some of them are related to the influence of sociopsychological factors. Since the logic of experimental analysis requires the comparison of task performance in the presence and absence of effect of an independent variable (hypothetical cause of expected effect), an experimental and control group of subjects are generally used in experimental studies. Under industrial conditions, it is difficult to isolate one group of people from another. As a result, the control group may compete with the experimental one and, as a consequence, there is masking of the influence of the tested factor (such phenomena were observed in the well-known Hawthorne experiments). Another situation could occur: the performance of the control group may worsen because its members will feel that they are injured by the absence of the innovations (which are usually attractive) that alter the working conditions in the experimental group. Awareness of the existence of such factors as competition or demoralization of the control group helps avoid hasty conclusions based on a superficial comparison of the results for control and experimental groups.

All of the foregoing is indicative of the danger of underestimating the role of interaction between the researcher and object studied, and of the need to work out the sociopsychological back-up for studies of work performance.

To this time, there is no clearcut classification of ergonomic investigative methods. The difficulty of developing such a classification is related to the fact that it must cover all areas of ergonomic research, which have not yet been definitively formed and continue to expand quite rapidly. The problem of classification of methods in ergonomics is analogous to the one that B. G. Anan'yev encountered when he tried to create a tentative classification of methods used in studies pertaining to modern human sciences [4].

A certain modification of the above classification is also applicable to ergonomics.

The methods contained in the first group are arbitrarily called organizational. They include, first of all, the system of methodological means that provide for a complex approach to research. The complex approach is used throughout the entire interdisciplinary study, while its effectiveness is determined by the end results thereof. The procedural basis of complex research is only beginning to be developed. The typical feature of interdisciplinary research is not the synthesis of results obtained on the basis of independent studies, but organization of a study in the course of which there is synthesis of the conceptions of different disciplines [2]. "The program of a complex interdisciplinary study is determined by the common object under study and separation of functions of different disciplines, periodic compilation of data and generalization thereof, mainly those pertaining to relations and correlations between diverse phenomena...." [4, p 302].

In spite of the fact that the specific routes of solving such problems have not been worked out, their very formulation has a positive effect on concrete ergonomic studies, calling the attention of ergonomists to problems of development of adequate research strategy and means of performing it.

The second group of methods consists of the existing empirical methods of obtaining scientific data. This group includes observation and self-observation, experimental techniques (laboratory, industrial, "formative" experiment), diagnostic methods (diverse tests, questionnaires of the contemporary types, sociometry, interviews and talks); analysis of processes and products of work (chronometry, cyclography, professio-graphic description, work method, evaluation of products, etc.); modeling (of objects, mathematical, cybernetic, etc.).

The third group consists of data processing procedures. They include various methods of quantitative and qualitative description of data.

Finally, the fourth group refers to various methods of interpreting the obtained data within the context of an integral description of the performance of MMS's.

The second group of methods is the most extensive and developed; one can single out a number of concrete procedures within this group, depending on the objectives and nature of the studies.

Experimental methods of studying the dynamics of various physiological functions are used in ergonomics [22]. The typical feature thereof is the wide use of electrophysiological methods: 1) electroencephalography (EEG), i.e., recording the electrical activity of the brain, which yields a number of characteristics of activity of neuronal ensembles of the brain under natural conditions; electromyography (EMG), i.e., recording the action potnential of muscles, which is a sensitive indicator of involvement in a dynamic relation or static work of specific muscle groups and plays an important role in evaluating muscle tone (essential in studies of positions and working motions); recording of galvanic skin reactions (GSR), the change in cutaneous potential difference that is a very fine indicator of man's emotional state; electrocardiography (EKG), i.e., recording of electrical activity of the heart, which is a reliable indicator of the state of the cardiovascular system; electrooculography (EOG), i.e., recording of the potential that occurs when the eyeball turns, which is used as an objective indicator of shifting of the eyes when examining some object. The recording of bioelectrical processes permits determination and quantitative evaluation of functional changes in the human body, that are difficult to detect upon direct observation and that occur under the influence of the most diverse changes in the environment.

The method of complex recording of psychophysiological functions, which is also called the polyeffector method, is used in ergonomics to study types of human performance that differ in content and complexity. This method gained more popularity in the study of functional states of man. The value of this method lies in the possibility of simultaneous recording of many psychophysiological parameters, which yields an integral idea about the work of the main functional systems of the body.

The use of biomechanical methods is also included in ergonomic research: high-speed photography, cyclography, cinecyclography, electric tensiometry--change in electric properties of sensors applied to parts of equipment deformed by man, electric recording of mechanical parameters by means of angular displacement sensors, bearing [reference] dynamographs and others [9, 28]. With the use thereof, man's motor activity is described from the standpoint of efficiency of various elements of the skeletomuscular system.

Wide use is made in ergonomics of methods of describing microclimate conditions--temperature, humidity, etc., methods of measuring and evaluating the intensity of radiation in the radio frequency range, methods of measuring noise level and frequency composition, methods of measuring and evaluating vibration, methods of assaying dust content of air, methods of assaying toxic substances in air, methods of measuring light and other methods of industrial hygiene [65] in order to study the conditions of man's industrial work.

The technique of anthropometric studies is used to solve various ergonomic problems [30]. Wide applications have been found for somatography--technical and anthropological analysis of body position and change in work posture of man, correlation between the size of man and machine. The results of such analysis are usually given in the form of graphs. Somatography permits calculation of the zone of easy and optimum range, optimum methods of organizing the work place with consideration of the proportional correlations between elements of equipment and man.

The essence of dynamic structural description of work activity, which is often called algorithmic analysis, consists of breaking down the work into qualitatively different elements, determination of the logical link between them, order in which they follow one another and calculation of a number of parameters that have a certain psychophysiological meaning [33]. Methods of systems-structural analysis of performance are important to ergonomics, in particular, the special methods of functional-structural and microstructural analysis [38, 39].

The armamentarium of methods of ergonomics includes many psychophysiological methods: measurement of reaction time, which has many variants (simple sensory and motor reactions, reaction of choice, reactions to moving objects, etc.); psychophysical methods (determination of thresholds and dynamics of sensitivity in various modalities); psychometric methods of examining perceptive, mnemic, cognitive processes and personality traits.

The sociometric methods of studying interpersonal relations, which are used in ergonomics, permit solving a number of pressing problems: establishing the existence of a preference or set expressed by an individual with regard to other members of a group or team in specific situations, describing the individual's place in the group as the subject sees it and comparing this to the reactions of other members of the group, expressing the correlations within compared groups by means of formal methods [56]. One of the most widespread methods of studying the compatibility of members of small groups is the homeostatic method, which has found applications in planning dynamic [operational] group performance [23].

The performance of ergonomic research requires development of adequate methods for making a quantitative evaluation of product quality. For this purpose, nonmetric and metric scaling is used, i.e., measurement that is construed as "putting in order a set of properties of real objects (object-related area) in relation to a set of signs (model area) by means of the ordering rule (f), which permits isomorphic representation of elements and relations between them in the object-related area by elements and relations between them in the model area" [61, p 154]. A formal model is obtained as a result of scaling, i.e., a scale that can be used as an analytical tool.

A distinction is made between nominal, sequential, interval and proportional scales. The nominal scale is based on attributation of signs to objects. It is constructed as a classification of objects studied according to presence or absence of a specific sign [tag] within the range of two or more observation categories (scale [dimensionality] of the tag). When plotting a sequential scale, in addition to equality and inequality, order is considered, i.e., the intensity of manifestation of the tag to be defined. The scale of intervals, which has all of the listed properties of the above-described scales, is characterized by the fact that the distance between two points of the continuum can be exactly specified and, for this reason, it is possible to evaluate the size of the intervals (Celsius temperature scale, standardized scales for psychological tests, etc.). All of the properties of the above scales are inherent in proportional scales. In addition, they have a natural or absolute zero point, for which reason one can compare the sums, differences, products and quotients, as well as determine the correlation between scale evaluations.

Rating scales have applications in ergonomics, and they serve as an ancillary means when making judgments about the degree of expression of a tag of some phenomenon or other. "Rating is a measurement, if the latter is construed as a comparison of the quantitative aspect of a tag to a certain gage. Rating scales should also be considered as such a gage, if different judges reliably derive largely coinciding evaluations and opinions of the same tag" [61, p 211]. The special significance of rating scales to ergonomics is that it is easier to derive a conclusion with their help about the intensity of complex tags. The method of expert evaluation is used in ergonomics to evaluate the arrangement of control consoles, data displays and other objects [68], when it is difficult to use estimation and experimental methods.

Ergonomics also uses and is instrumental in further development of methods of cybernetics, which includes in the optimization concept the requirement of optimum human control of performance in complex MMS's [12, 87, 88]. There is much in common between ergonomic and bionic methods. Methods of preparing quantitatively substantiated recommendations on optimum decision making are also included in the armamentarium of ergonomics. Use of methods of automatic monitoring theory, information theory, queueing theory and others in the study and design of MMS's makes it necessary to devote increasing attention to substantiation of applicability of approaches, demonstration of their basic capabilities and equivalence to the specifics of the problems to be solved [64].

Use of the methods of systems analysis, which are related to macrodesign of complex systems, i.e., choice and organization of functions and structure as a whole, is largely involved in causing the formation of ergonomics as a planning [design] discipline [1, 87, 88]. General methodological approaches are being developed for solving the main tasks of ergonomic planning, which is an element of overall planning [or design] of the MMS, the objective of which is to substantiate the ergonomic specifications, implementation thereof in the form of properties of the planned system and expert evaluation of the results of designs [14, 24, 29, 35, 41, 42]. Rational economic planning is based on planning the performance of man (or group of people), development of the methods of which constitutes one of the most difficult tasks. They can be fulfilled if a system of methods is created, since none of the methods is universal and suitable for analysis of all aspects of the problem of planning activity. The mutual complementarity and interaction of the methods does not minimize the need to determine which method is the leading one, depending on the objectives and tasks of specific studies [17].

As we have shown above, the methods used in ergonomics are diverse, and it is not deemed possible to provide a detailed description of each of them, even in a special textbook. Special attention will be given to methods of observation and interrogation, studies of man's executory and cognitive activity, evaluation of functional states, modeling and use of computers in ergonomic research.

3. Methods of Observation and Interrogation

Observation refers to the purposeful, organized and systematized consideration of the object under study. It is also very important to clearly record the results of observations, in order to reproduce them and use other forms of verification. Observation methods have undergone significant change in recent times because of the use of various recording and other equipment (photographic, cinematographic, acoustics, television). At the same time, greater requirements are being made of sophistication of observation, primarily from the standpoint of proper formulation of the objective of observation, accuracy thereof and broadness of consideration of the phenomenon described.

In ergonomics, observation is often an element of an experimental study. Organization of observation involves solving the following problems: a) definition of the task and objective of observation; b) choice of object, subject and situation; c) choice of method of observation that has the least influence on the object studied and assures gathering the required information; d) choice of method of recording the observed phenomenon; e) processing and interpretation of the obtained information [78]. When organizing observations it is imperative to take into consideration the fact that the presence of an observer has an appreciable influence on performance. One can describe work performance in sufficient detail by means of the observation method, supplemented with time and motion studies of all operations in order of their performance.

In professiographic studies, a preconceived and prepared observation scheme is of particular importance. We submit below two observation schemes for the purpose of analysis of the work place, working position and working motions. The first was compiled to study the performance of dispatchers and the second for that of coil winder operators. The work of dispatchers was studied for the purpose of preparing the ergonomic specifications for the desk chair, and that of the winder operators in order to reorganize the entire work place [74].

Observation Scheme No 1

1. Specifics of dispatcher work according to involvement of sense organs and parts of the body (hands, legs, vision, hearing) involved in the work.
2. Specifics of body position: fixed pose, mobility in relation to seat, console.

3. Angle of inclination of the body: negative (forward), straight, positive (backward).
4. Height of trunk support point (back) abov seat.
5. Height of console and angle of inclination of working panel.
6. Work of the hands (right, left, both).
7. Hand position in range of reach: according to depth (maximum, near) and width (on the right and left).
8. Conformity of console dimensions to areas of easy or optimum reach of motor field of work place.
9. Hand support points (elbows, forearm).
10. Position of legs (right, left).
11. Conformity of console size with zones of easy or optimum reach.
12. Determination of support part of seat: front, middle, rear.
13. Possibility of rest beyond the work zone.

Observation Scheme No 2

1. Specifics of work according to involvement of sense organs and parts of the body (hands, feet, vision, hearing).
2. Specifics of body position: fixed pose, mobility in relation to seat and bench.
3. Angle of inclination of the body: negative (forward), straight, positive (backward).
4. Angle of inclination of the head: negative, straight, positive.
5. Involvement of hands: constant (right, left, both), periodic (right, left, both).
6. Hand position in the zone within reach: depth (maximum, near), and width (on the right and left).
7. Conformity of console size to areas of easy or optimum reach of motor field of work place.
8. Involvement of legs: working (right, left), support (right, left).
9. Position of working leg during period of no action: on pedal, floor, footrest, no support.
10. Position of supporting leg: on the floor, footrest, pedal, no support.
11. Conformity of bench size to areas of easy or optimum leg reach.
12. Use of footrest (yes, not; for right, left, both feet).
13. Distance between mean axillary line to mounting (transverse axis of bench).
14. Determination of supporting part of seat: front, middle, rear.
15. Attitude of worker [female] to improvements made in chair (positive, negative).

The results of observation can be recorded in the form of a table, to which instructions are attached for filling it out.

The interrogation method is used extensively to gather information about the structure of the work process, nature thereof and the individual's attitude toward his work.

The interrogation can be regulated, i.e., there is prior preparation of questions that are the same for all subjects and listed in a strictly specified order, or unregulated, in the form of conversation with the subjects, adhering to the general plan.

The conversation method requires certain skills and even talent. It is recommended for interrogation of a small number of workers. The conversation method clarifies answers to posed questions, explains questions that presented diverse difficulties (for example, terminological), and it also permits recording a subject's comments that are beyond the framework of the questions but of some interest.

Usually, there is a combination of questions in the questionnaires that are prepared specially for each concrete case, with due consideration of the distinctions of the occupation under study. The questionnaires must be prepared in accordance with the tasks and objectives of the ergonomic study. Before preparing a questionnaire, the researcher must observe the workers for a certain time or, better yet, learn the main work operations himself. Then the first variant of the questionnaire is prepared, and it is tested on a small number of subjects. At this stage, the clarity and formulation of questions, fullness of the list of questions are checked; determination is made of the order of the questions in order to avoid undesirable influences; additional questions are entered; overlooked aspects of the problem under study are explained; the format of the questionnaire is tested to make sure it would not elicit a negative attitude on the part of the subjects [51].

The complex approach implies the use of interrogation methods that have become widespread in ergonomic research in the form of questionnaires and interviews. The interrogation methods, like observations, are used in ergonomics to work out working hypotheses and in order to enlarge upon data obtained by other methods. In using the interrogation methods, the nature of the questions, their formulation and direction are very important. A distinction is made between open questions (free answer) and closed ones (multiple choice answers).

The following must be taken into consideration in order to formulate the questions properly: 1) each question must be logically complete; 2) one should avoid little-used foreign words, special terms and words with dual meaning; 3) one should not pose questions that are too long; 4) if the question deals with a subject that the worker is not familiar with or to answer which he does not have the necessary vocabulary of special terms, the appropriate explanations must be furnished; 5) each question must be as concrete as possible; 6) one should either indicate all possible variants of an answer that the subjects must bear in mind, or give none at all; 7) one must provide to the subject only the variants of answers that could be acceptable to the same degree; 8) the question should be formulated in such a manner as to avoid stereotype, banal answers; 9) one should take care not to include in the question words that could elicit a negative attitude of the subject; 10) the questions should not be suggestive in nature [51].

As an example, we are submitting two types of questionnaires. The first was used to study the work of unified power/system dispatchers and dispatchers distributing tickets at railroad stations. The objective of this study was to develop an optimum variant of a dispatcher's chair. For this reason, the questions were directed toward determining the subjective opinion about the existing chair and wishes concerning improvement. The second questionnaire was used to study the work of transformer coil winders in order to redesign the work place.

Questionnaire No 1

A. Surname, name, patronymic. B. Age. C. Position. D. Tenure. E. Length of work day.
1. Is it comfortable for you to sit (yes, no)?
2. What causes discomfort?
3. In what part of the body is their pain (back, lumbar region, arms [or shoulders])?
4. Is it convenient to work with the hands (yes, no)?
5. Should the seat turn (yes, no)?
6. Would it be desirable for the chair to be on casters (yes, no)?
7. Is a back or lumbar region rest needed while working (yes, no)?
8. Is a flexible back needed (yes, no)?
9. Should the seat be flat, tilted backward, forward?
10. Are armrests needed (yes, no)?
11. At what level should the back of the chair be (scapula, shoulders, lumbar region)?
12. How should the seat be (soft, semisoft, hard)?
13. How should it be upholstered (fabric, oilcloth, leatherette)?

Questionnaire No 2

A. Surname, name, patronymic. B. Age. C. Position. D. Tenure of work as winder [female]. E. Length of work day. F. Bench number. G. Bench type. H. Output norm per shift. I. Type of coil.
1. Is it comfortable for you to work (yes, no)?
2. What causes discomfort?
3. Which parts of the body get the most tired in the course of work (back, lumbar region, shoulders, neck, arms, legs)?

4. In which part of the body and when is pain felt (back, lumbar region, shoulders, neck, arms, legs; during work, at the start of the day or after work)?
5. Do you experience physical tension when turning control levers, depressing pedals (yes, no)?
6. Is it comfortable to work with the hands (yes, no)?
7. Is the size of the work bench satisfactory: height (yes, no), depth (yes, no), width (yes, no)?
8. Is the height of the chair satisfactory (yes, no), is its shape satisfactory (yes, no)?
9. Is a back required for the chair (yes, no)?
10. At what level should the back support be (scapula, shoulders, lumbar region)?
11. Is a flexible chair back desirable (yes, no)?
12. How should the seat be (soft, semisoft, hard)?
13. How should it be upholstered (fabric, oilcloth, leatherette)?
14. Should the seat turn (yes, no)?
15. Are armrests needed (yes, no); for both arms (yes, no); for the left (yes, no)?
16. Is a footrest needed (yes, no)?
17. Do you have to stand up often during work?

As we see from these questionnaires, first general questions are posed: "Is it comfortable for you to work?" "Is it comfortable for you to sit?" "What causes discomfort?" the answers to which are not very informative but help establish contact with the subjects. Then follow questions about the subjective attitude toward elements of the work place, for example: "Is the size of the console satisfactory (height, depth, width)? Then there are questions about how the worker feels. Last are the subject's wishes.

As a rule, the interrogation is conducted right at the work place, during work. But it can also be done in the laboratory using experimental samples of products or an experimental stand.

The effectiveness of the interrogation method depends largely on the level of education of the subjects and their occupational experience. For example, power system dispatchers are experienced and highly skilled specialists who work under very difficult conditions. Before becoming dispatchers they had worked for a certain time at other power facilities. When they were questioned, exhaustive answers were obtained.

The ticket distributing dispatchers at railroad stations are mostly women with secondary or incomplete secondary education. Their work experience is very negligible, so that they answered "I don't know" to many questions. As for the women working at the plant, they responded differently to general and specific questions. For example, they almost always answered in the affirmative to the question, "Is it comfortable for you to work?" There were more variations in answers to specific questions. The women complained of general fatigue, localized pain, mentioned flaws in the design of the bench, chair, etc.

The data obtained from the interrogation are submitted to statistical processing. The processing results are presented in a descriptive form, and a distinction is made between observation data and the subjective comments of a subject. The material described is accompanied by tables and charts of relevant data. The tables should indicate the percentile of a given indicator in relation to data from all surveys.

When observation is combined with interrogation, it is important to find a rational method of recording answers. Best of all is to provide different variants of answers in the record (or observation scheme). Simple answers should be given to simple questions: yes, no, don't know. If possible, one should plan in advance the questions to which more expanded answers may be given.

It is particularly important to have the same [general] observation outline when several researchers are working concurrently. This permits combining and comparing the results. However, in such cases, good instructions must be prepared on how to conduct observations and record the results.

Objective (instrumental) research methods imply the use of various instruments and equipment. The following are objective methods: measurement of various characteristics of the industrial environment (lighting, noise, vibration, etc.), metric measurements, time studies, measurement of physiological parameters (pulse, respiration, EKG, etc.), measurement of psychological characteristics.

The first and last two methods require the use of rather complicated monitoring and measuring equipment. There is no such restriction on the use of the second and third methods.

When working on problems of improving organization of labor and increasing its efficiency, data pertaining to the size of the industrial facility, different elements thereof, location of windows and doors, as well as data about the dimensions of equipment, work places, etc., may play a substantial role.

Spatial organization of the work place affects the nature and quality of working motions, working position, etc. For this reason, analysis of spatial organization of the work place must be made at the first stages of professiographic studies. We submit below an outline [scheme] for analysis of spatial organization of the work placr when it is to be remodeled [74].

Outline for Analysis of Spatial Organization of Work Place

1. Determination of main types of sensory activity (visual, auditory, visual and kinesthetic, etc.).
2. Demonstration of nature of motor activity.
3. Spatial determination of areas of sensory activity.
4. Spatial determination of areas of motor activity.
5. Making a sketch of the location of the main equipment in relation to the worker, with indication of main sensory and motor areas.
6. Making a sketch of location of ancillary equipment in relation to working individual.
7. General sketch of work place.
8. Analysis of the obtained data.

The work is done in the following manner.

Determination is made of the main and ancillary types of equipment, zones of motor and sensory activity on the basis of observation of actions during work. Then the main working position and pose are determined by questioning and observing.

The sketches make it possible to detect inconsistencies between the existing spatial organization of a work place and psychophysiological and anthropometric characteristics of man. Subsequent analysis thereof, with due consideration of the main ergonomic requirements, makes it possible to offer recommendations pertaining to optimum remodeling of the work place.

Time studies, i.e., keeping a record of changes as a function of time in some parameters of the work process using a stopwatch or clock, are one of the methods of objective observation. Time studies permit determination of various time-related characteristics of the work process, on the basis of which one can determine the time spent on performance of various operations and elimination of interference, actual time spent per unit of production and the norm for the shift, time lost on actions that have an indirect effect on work activity (leaving the work place, lack of materials, etc.), determination of the dynamics of motor and sensory activity, and other indicators of efficiency [fitness]. A time study should not affect the normal progress of a work process. When studying an occupation, time studies are made of both separate work periods and the work day as a whole, in different shifts, days of the week, etc.

As is the case with any method of objective study, time studies are preceded by special preparations, consisting of determination and study of the work operations. Singling out the operations is the main prerequisite for proper time studies.

One of the variants of a time study is chronography, which consists of recording the time characteristics in graph form. Chronography is used under industrial conditions to analyze the state and dynamics of a man's motor and sensory activity during the owrk process.

Working motions (speed, direction, amplitude) and working pose, the number of visual, auditory and tactile elements addressed to the work object, information displays, etc., may be the object of a chronographic study.

4. Methods for the Study of Productive and Cognitive Activity

The content of methods of studying movements is determined by the aggregate of parameters characterizing the process of making a movement, on the one hand, and means of recording these parameters, on the other.

Singling out the set of parameters that describe the process of performing a motion is related primarily to the choice of a certain conceptual model that describes the work of a motor system (biomechanical model, physiological model of the myoneural system, etc.). Awareness of this circumstance enables us to outline an approach to the classification of methods of studying motion. Thus, kinematic (characteristics of spatial motion) and dynamic (force) parameters of movements and means of recording them involve development of a biomechanical model of the motor system, while electromyographic methods owe their existence to development of a physiological model of the neuromuscular system.

We should begin the description of methods of studying motion with the cyclogram, which is a photograph of a a movement on a stationary plate. For this purpose, fluorescent marks or electric lamps are secured to the movable parts of the subject's body. A shutter operating at a specific frequency, which shuts the lens, is placed in front of the camera. The successive positions of the lamps are recorded on the plate; these lamps move in the course of a motion, together with the kinematic elements of the body. This method cannot be used to record complex cyclic motions. For kymocylography, the film on which information about lamp movement is recorded moves uniformly and slowly. In this case, the cyclic motions extend over the recording film. These methods of cyclography and kymocyclography are intended for planar recording of movements.

Various modifications of the above methods are used to study spatial movements: stereoscopic photography, i.e., photography with two lenses with parallel optical axes, photography with lenses having converging optical axes, etc. The "mirror method" is also used, which yields photos of an object from two different points using one camera and one shutter. Two images of the same object hit the camera lens: one directly from the object and the other reflected at a certain angle by a mirror. This method provides for very accurate spatial readings and convenient analysis of experimental data.

Analysis of cyclograms is a rather labor-consuming process. Photographic measurements and nomograms are used to analyze the displacements of various points of the body in space.

In the former case, the cyclogram negatives are printed on photographic paper using an enlarger. In the same manner, a millimeter or half-millimeter grid is superimposed on the print, which alleviates significantly the work with the material and increases accuracy of measurements. The nomogram method simplifies determination of all three spatial coordinates of mirror cyclophotograms.

Cyclography can be used for rather precise analysis of certain motor acts. A method has been developed for cyclography of arm [or hand] movements during haptic (blind) passage through a maze, on the basis of which it has been possible to differentiate between orienting-exploring and productive [executor] hand movements. Motions serving to construct an image and for recognition were isolated from tactile movements by means of cyclogrpahic tracings. In such cases, motion was also recorded in one plane.

There are more methods that are used to study various motor problems. They include methods for measuring the intensity of magnetic and electromagnetic fields, tensometry, holography, radar, etc. The intensity of magnetic and electromagnetic fields is measured to study relatively low-amplitude and angular motion. The tensometric method, like the goniographic one (the latter will be discussed in greater detail below), is used for macro- and micro-angular measurements. Tensometry has gained particularly wide use for measurement of macroscopic changes in an articular angle when studying tremor. Television, holography and radar have not yet found the development they deserve in the field of motion studies. Television is used mainly as a display [indicator] device. This is attributable to the fact that there are some difficulties involved in obtaining spatial parameters in the form of electrical signals that are convenient for analysis of movements of an object with the use of a television system. Extensive introduction of computers in the field of ergonomic research is a means of overcoming these difficulties. Holographic and radar methods are still used quite seldom, although they are rather promising. Probably goniography is the most convenient and widespread method for measurement of angular displacement. Goniography, which yields readings about changes in spatial position of an articulation of a kinematic chain, is used for artificial feedback. However, it is a rather complicated technical task to obtain electircal signals equivalent to the spatial displacement of an end point of an open kinematic chain. For this reason, there are substantial limitations for the use of this method to study spatial displacements of an object.

The armamentarium of methods for the study of executor activity also includes experimental situations that are organized in a special manner.

These situations include diverse variables, which can be viewed as essential conditions determining performance of motor tasks. Tracking is one of the widely used experimental situations in studies of executor activity.

As related to the study of man's executor activity, the tracking situation can be considered on two planes: as a laboratory model of various types of practical human activity (work of radar station operator, driving various forms of transport and others) and as an experimental procedure for solving certain theoretical problems that arise when analyzing motor behavior.

In the tracking situation, the subject is asked to perform a movement, the parameters of which (speed, direction, amplitude, time) should conform [satisfy] with the parameters of a moving target, with which the subject's movement is coordinated. The specifics of the tracking situation (unlike a "precision task" and that of "preserving stability" of motion parameters), consist primarily of the fact that, in this case, the motor behavior of the subject is rigidly determined for virtually all parameters of motion.

The following terms are generally used to describe tracking: setting or standard object (or "target")--an object, the law of motion of which is set by means of a certain input function; controlled object (or "kursor" [tracking device?]), which is the object that the subject controls by handling a control element. The motor behavior of the subject in a specified situation is expressed by the motion of the controlled object (output function).

Thus, a tracking problem consists of having the value of the output function correspond exactly to the value of the input function at the appropriate point in time, while the subject must work out a corrective action to eliminate the discrepancy between values of input and output functions on the basis of perceived information. Two classes of variables determining a tracking situation are distinguished, depending on how rigidly the subject's motor behavior is determined and what information he receives about tracking.

The first class of variables is related to the type of input function used, which is determined primarily by the nature of dynamics of the input function in time. A distinction is made between continuous and discrete tracking problems. In the case of continuous tracking, the parameters of the input function change continuously. But if the values in input function change in "jumps" at certain points in time, we are dealing with a discrete tracking problem.

The second class of variables is related to the nature of information about how the tracking problem is solved. A distinction is made between pursuing [fillowing] and compensatory tracking, depending on whether the target is moving or not. In the case of pursuing tracking, the subject receives three types of information: about movement of the target, actual "pursuit" movement and discrepancy (or error) between position of the target and tracking device. In the compensatory tracking situation, the target does not move and the subject must hold the controlled object on it, the latter being subject to perturbing factors and deviating from the required position. In this case, information about the subject's regulating action on the controlled object and characteristics of input function cannot be distinguished. Only information about the magnitude of deviation of the tracking device from the target is used to solve the problem.

The main objectives of research were formulated differently, depending on whether tracking was studied for applied or theoretical purposes, and specific experimental procedures were designed for the performance of specific types of tracking. Thus, when using tracking as an applied method, compensatory tracking was and is generally used. This is attributable primarily to the fact that, in this case, one is mainly interested in analysis of different variables that influence the degree of discrepancy between the position of the setting and controlled objects and displacement of the control in order to minimize mistakes. For this reason, it is desirable to simplify as much as possible the experimental procedure and to rule out of consideration the influence of "superfluous" channels of information on the problem-solving process. Conversely, when using tracking to analyze theoretical problems (for example, the role of efferent systems in regulation of movements), a rich information field in the situation of pursuing tracking offers wider possibilities.

The use of tracking as a means of analyzing productive activity requires the choice of different variables determining the process of solving a motor problem and modeling them under experimental conditions (or through operator training on simulators). The following are the most widespread variables of tracking: time lag (i.e., interval between controlling action and change in parameter regulated at the input), simultaneous control of several parameters (multifactor control), including interdependent ones, manipulation of visual feedback (interruption, inversion) and an additional problem. Introduction of these variables, as well as the use of various forms of tracking combined with other methods of analysis of motion, makes it possible to solve a wide range of applied and theoretical problems.

Development of an adequate method of recording and analyzing the time and space tracing of productive [executor] actions is a mandatory prerequisite for successful studies of motor acts. An experimental stand for the study of instrumental motor skills meets this requirement.

The functional flowchart of the experimental stand (Figure 1) includes the following: a system to control the object; color television indicator; control computer which operates both in the calculating mode for multi-dimensional statistical processing of the results, and in the mode for control of the experiment.

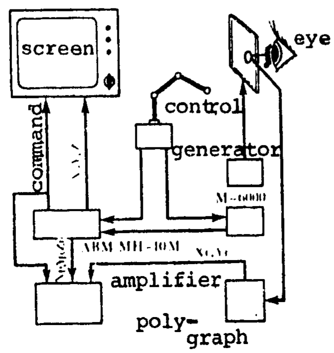

Figure 1.
Flowchart of experimental stand

Key:
ABM) analog computer
M-6000) computer

The object control system includes a multigrade control element, tensometric amplifier and operational amplifier unit.

The manipulator type control element (sensor of spatial displacement of operator's hand) is a parametric model of the human hand; it is constructed in the form of a hinged joint of three kinematic elements by means of simple hinges, and it has three degrees of mobility. Any spatial displacement of the point to which the operator applies force is transformed into the corresponding change in angles formed by the kinematic system of the control element. The input parameters are the current values of trigonometric functions of angles formed by the sine-cosine sensors placed on the axes of rotation of the element. From them, a spatial mathematical model of the control in relation to a right-angle Cartesian system of coordinates is formed in the analog computer unit. The design of the control element permits retention of the content and natural direction of the operator's manual movements, although the control system has provisions for disrupting the homogeneity and conformity of the motor and sensory fields by means of inputting coefficients of space compression or electrical inversion of the direction of similar vectors.

The color television screen ["indicator"] used in the experimental installation could be described as deceptively [illusory] descriptive, since an impression of the volume of test and controlled signals is gained by altering the magnitude of the controlled signal.

The indicator is based on a commercial color television receiver with a control unit. Light signals of different colors are formed on the indicator screen in accordance with the analog electrical signals inputted in the control unit. An impression about the volume is obtained by controlling the change in area of lit signals. The lights on the screen can move horizontally (X), vertically (Y) and by changing the lit area (Z). Independent control of the light stimuli for parameters X, Y and Z makes it possible to use them to code the spatial coordinates of displacement of the control object and to form a system of reference for the operator's sensory field. The controlling coordinate signals are formed in the object control unit according to equations of relationship between spatial movement of the operator's hand and the control element.

The control computer can be operated in two modes, active and calculation. The programs for control of the experiment and processing of obtained results are run by an interpreting system on an M-6000 computer of the ASVT [modular system of computer facilities]. The experiment is conducted in the mode of dialog with the computer in accordance with the principle of priority servicing of the following devices for communication with the object: modules for input of discrete information of experimenter's and subject's control signals; modules of group control of output of discrete information from test signals of the operator's visual communication channel; contactless commutator; analog-digital converter that receives analog signals concerning the spatial position of the subject's hand.

The use of a computer [digital] in the experiment line makes it possible to display on a screen trajectories of motion that change in complexity, number of elements and components; to introduce disruptions in the customary actions manifested by changes in trajectory of movement; to introduce inversion, i.e., disrupt the usual correlation between perceptive and motor fields. Connection to a computer has alleviated the labor-consuming job of manual processing of tens of thousands of measurements and made it possible to obtain the precision- and speed-related characteristics of motions directly during the experiment.

The multipurpose experimental stand we have described permits recording time and space--speed and precision--parameters of the process under study. Movements of the lever are recorded on the tape of a multichannel polygraph in the form of three components on the X, Y and Z axes. The signal from the computer concerning presentation of a new matrix and subject's signals of matching with each element of this matrix are recorded on a separate channel.

Movement of the controlled spot was recorded simultaneously on a tape recorder as well, which permitted reproduction of the trajectory of the movement on a plotter, as well as to input the experimental data in the computer for an estimate.

The use of microstructural analysis, the purpose of which is to single out rapid components of an integral action, made it possible to distinguish the following stages for each component X, Y and Z of spatial motion:

latent, phasic (performing), and the stage of checking and correction. Figure 2 illustrates an example of a tracing of a shift by one element in one of the trajectories of motion. It clearly shows that there is a significant latency period for each component preceding motion. After active movement of each component, one records a long period of relative rest which precedes the subject's signal that the controlled spot is matched with a matrix element. This period can be considered the period of corrections, which is characterized by fine motions referable to some component or other, and period of checking the quality of matching. As can be seen in this figure, the duration varies for each component of the stages: there is some lag in programming for one component, as compared to another, i.e., successive planning for each component is possible. Analogously, there is also a certain shift of performance and checking.

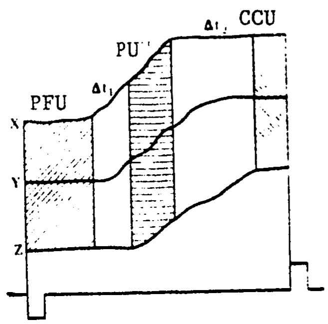

Figure 2.
Diagram of isolation of components of an integral action
T_{PFU}) Tmin. latency
T_{PU}) T_{total} - ($T_{max.lat.}$ + $T_{check.}$)
T_{CCU}) Tmin. checking [or control]
Δt_1) Tmax.lat. - T min.lat.
Δt_2) Tmax.check. - Tmin.check.

These data served as the basis for making a distinction between so-called "net time" of unit-stages: PFU--program forming unit, PU--performance unit, CCU--checking and correcting unit, as well as two stages of scatter: Δt_1 includes both planning and performance, and Δt_2, which combines performance and checking. The "net time" of each unit is the time when the components of motion function in terms inherent in this particular unit, be it planning, performance or checking. The scatter, which is characterized by the value of Δt_1 and Δt_2, provides information about scatter, not only within one stage, but also between stages of motion, describing the degree of spatiality of the performed action.

Use of the multipurpose experimental stand offers wide opportunities for studying processes of control and construction of motion.

The use of modern methods of analysis of cognitive processes is found to be quite effective in solving a number of applied problems.

The capacity for visual detection and discrimination of critical elements, presented against the background of others that differ in some tags and coincide in others (radar screens, photos of events in Wilson chambers, x-rays, etc.), is of decisive significance for a number of modern operator occupations.

Optimization of this type of activity is related primarily to analysis of the properties of the visual system as a filter of time and space frequencies. Psychophysical studies of man and psychophysiological studies of animals [21] revealed that there are information processing channels in the optic system that are specific for certain spatial frequencies of an image. Maximum sensitivity to sinus-modulated distribution of brightness, which has a specific spatial frequency, is inherent in them. Thus, the visual system is structurally and functionally capable of frequency analysis of any image, just like a certain function can be analytically presented in the form of the sum of sinusoidal components when it is submitted to Fourier expansion.

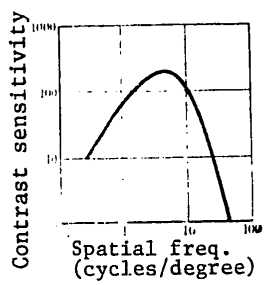

Figure 3.
Function of contrast sensitivity of the human visual system (after Campbell and Robson, 1968)

The characteristics of these frequency-specific channels determine the function of contrast sensitivity of the sight system (Fgiure 3), which indicates the extent to which various spatial frequencies of an image are amplified or, on the contrary, attenuated as they pass through the optic system.* In spite of the fact that, by virtue of the nonlinearity of these transformations [85], the functions of contrast sensitivity adequately characterize the capabilities of our vision only for near-threshold intensities of stimulation, it contains appreciably fuller information than numerous traditional parameters of "acuity of vision." Moreover, in evaluating any means of visual reflection, the question arises, first of all, as to whether certain information can be perceived at all. For this reason, the problem of supraliminal nonlinearity of the visual system in this context is not so important.

Let us consider more carefully the function illustrated in Figure 3. The descent of the right arm of the curve of sensitivity in the area of high spatial frequencies conforms with the well-known fact that rather fine details are indiscernible. This flaw of sight is compensated by various means of enlargement of the angular dimensions of the image. Less known

*Contrast sensitivity functions are plotted by determining the minimum depth of modulation of sinusoidal distribution of brightness distinguished from a homogeneous field.

is the fact that there is diminished visual sensitivity to low spatial frequencies reflected by the decline of the left part of the curve. It is very important to bear this in mind, for example, in roentgenology, since soft tissues and tumors are represented on the films by expressly low-frequency, gradual signs of brightness. Thus, depending on the part of the spectrum of an image containing critical information, it may be desirable not only to enlarge, but reduce the image. Since the range of possible changes in angular size of details is quite large (about 1:20), it is obvious that this cannot be achieved by a simple change in distance of the photo.

Supplementing analysis of spatial sensitivity with information about the time-related resolution sensitivity of the eye is an interesting development of this approach. In particular, such studies established that discrimination of features referable to the shape of objects diminishes if the time and space conditions of presentation coincide with those under which seeming (stroboscopic) movement is observed [18]. It is a known fact to anyone that there is analogous perception of rapidly moving real objects.

The design and development of multidimensional devices for displaying information is a similar [close] area of applied research that has experienced the strong influence of experimental psychology. Here, the designer's task is to report to the operator, as simultaneously as possible and without interference, a multitude of diverse information, which determines separately or in some combination the accuracy of their solutions. The entire history of work in this field shows that our ordinary objective perception, which integrates into a single, integral pattern, not only diverse sensory information but data stored in memory, is an ideal example of solving this problem. For this reason, all of the more interesting work in this field is based more or less on the use of ecologically natural mechanisms of perceptual processing, the details of which are demonstrable by the diverse techniques used to study perception. Thus, psychophysical studies of perception of time and motion [84] originated an entire family of display devices of the contact analog ("conalogs") type that have been well-described in the special literature. Combined with the possibility of referring to precise digital information about each of the critical parameters of a situation, the "conalogs" permit concurrent consideration of multidimensional dynamic spatial information about the position of objects such as an aircraft, rocket, submarine, etc.

There is a great potential for use of the reserves of graphic visual memory for identification purposes. As shown by the most recent studies, while remembering random visual structures suffers from the same restrictions as remembering meaningless verbal material [90], the memory of subject-related slides of landscapes, even when they are rather monotonous in topic, is much greater in volume and duration than all other known forms of memory.

The work of Swiss authors [91], who were given the task of developing algorithms that would permit visual discrimination between genuine and counterfeit banknotes could serve as an example, perhaps not the most important but definitely quite demonstrative, of using the mechanisms of objective perception as a basis. The difficulty of this task consists of the fact that there is a considerable number of spatial parameters of a drawing (distance between elements of the drawing, their size, etc.), each of which is normally characterized by a certain range of variations. Interestingly enough, an attempt to represent these parameters in the form of abstract figures--closed polygons (Figure 4)--failed just as much as the use of data in digital form. Conversely, representation of these parameters in the form of arbitrary pictures of human faces (Chernov algorithm), as can be seen in Figure 4, solves this problem rather easily.

Procedures such as recording eye movements, chronometric analysis, factor experiments, etc., are also used with success for studies of information retrieval processes [8, 89]. Development of these directions of research, which are already quite traditional from the standpoint of practical use, has led to more comprehensive analysis of the possibility of utilizing the spatial characteristics of eye movements to optimize complex sensorimotor coordinations. Experimental analysis of information retrieval processes, which take place in the endogenous space or, more precisely, internal, subjective spaces of operator memory, rather than exogenous, is a new direction of research.

The time study of recognition processes is the prototype of most such studies: the subject must determine as rapidly as possible whether a presented object belongs to a previously shown "positive" set [92]. The typical results consist of the fact that the time of both positive ("yes") and negative ("no") reactions is a linearly growing function of the magnitude of the "positive" set (Figure 5). In addition, the slope of both functions is about the same. This shows that the search for information among elements of the "positive" set represented in memory is a successive process, in the first place, and an exhaustive one, in the second. In other words, this is a process that continues until all elements of the set are checked in memory, even if the identity of the presented element with one stored in memory had been established at one of the intermediate stages of retrieval. If the search had stopped immediately after establishing that they are identical (self-ending search), it would be necessary to examine twice as many elements in negative tests than positive ones. For this reason, the slope of the function for negative answers must be twice the slope of the function for positive ones.

Interestingly enough, in some studies results were obtained that appeared to contradict this analysis: the functions for negative reactions were somewhat steeper than for positive ones, but not to the extent that one could have expected in the case of self-ending retrieval [83]. However,

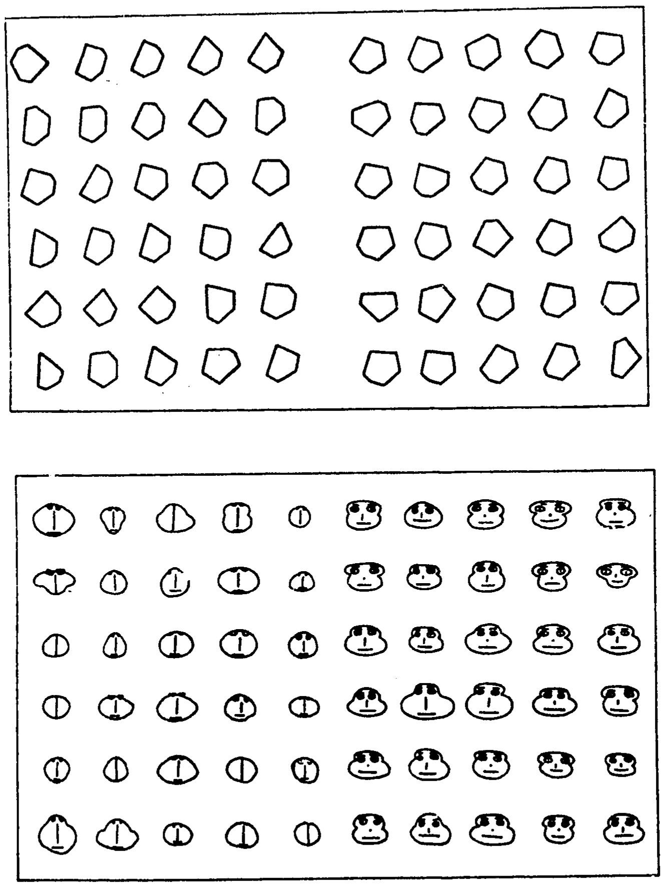

Figure 4. Examples of abstract and conventional images: genuine banknotes on the left and counterfeit ones on the right (see text).

a more thorough analysis revealed that these results are artefacts of the practice, unfortunately still prevalent in psychology, of averaging individual data. The results for one part of the subjects turned out to correspond exactly to an exhaustive type of search, whereas the results for another, smaller group of subjects corresponded rather well to the self-ending type. Somewhat paradoxical is the fact that the latter subjects, who seemingly chose the more rational work strategy, actually performed the task less efficiently than the first group of subjects.

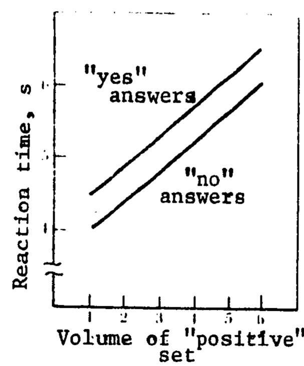

Figure 5.
Typical results of a study of retrieval from memory. A case of successively exhaustive search (after Sternberg, 1975)

This last example leads us directly to a question, which is of utmost importance to ergonomics, about the description and systematization of individual differences in characteristics of work activity. The classical methods of the Soviet school of differential psychology [52, 69] lay the foundation for ergonomic procedures of typology and concrete individual psychological analysis. In addition, the development of conceptions of the microstructure of various forms of cognitive and productive activity also permits offering a psychologically competent evaluation of differences in the functional systems that perform these elements in a specific individual. It becomes possible to overcome such deep-rooted empiricism in differential psychology, which deliberately limits itself only to studies of the correlation type. A more detailed example of this approach is discussed in the section dealing with methods of analysis of functional states (see also [40]).

5. Methods of Evaluating Functional States

In the modern literature, a distinction is usually made between three types of criteria with which one can evaluate the state of a subject: physiological, behavioral and subjective indices [40, 79]. However, the classification of Bartlett [80] is more distinct; he singled out physiological and psychological indices. The last group includes criteria of efficiency of performance of various psychometric tests and analysis of subjective symptoms of concrete types of functional states.

Physiological testing methods: The efforts of a large group of researchers are directed toward the search for parameters of changes in functional state of the body, be they indirect, but immediately recorded [20, 57]. Traditional reference to this class of phenomena is attributable to a number of important reasons. The main one is the possibility of an objective description of observed phenomena. In addition, the use of physiological parameters expands appreciable the range of manifestations, accessible to description, of the studied dynamics of behavioral reactions, and creates the possibility for at least hypothetical correlation of psychological phenomena to their organic basis. The basic possibility of making a quantitative evaluation of functional changes in any system is a rather important argument in favor of using physiological parameters.

The most diverse indices of central nervous system function are considered as possible indicators of the dynamics of functional states. They include, first of all, the electrophysiological parameters of the EEG, EMG, galvanic skin response, evoked potentials, as well as heart rate, arterial pressure, vascular tonus, diameter of the pupil and many others (Figure 6). In addition, there is intensive development of studies of biochemical changes in the body associated with various functional states. On the basis of special techniques, complex and multieffector recording methods are being developed.

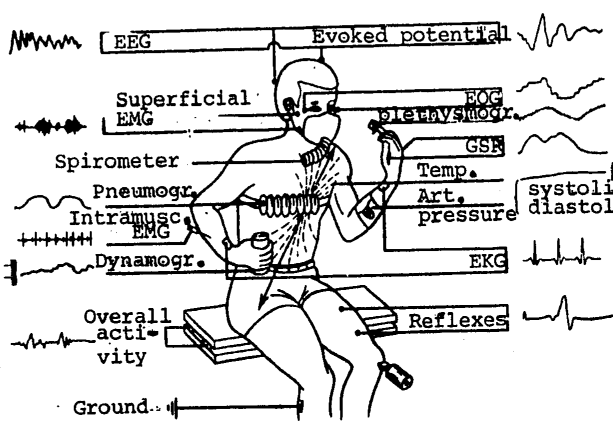

Figure 6. Multichannel recording of the most frequently studied types of human bioelectrical activity

Traditionally, changes in parameters of electrical activity of the brain are considered as a direct indicator of the dynamics of activation levels. Typical changes in the EEG are being related to various types of functional states. Thus, the reaction of desynchronization of α-rhythm combined with appearance of slow wave (γ and θ) activity is interpreted as appearance of developing fatigue. As fatigue increases, these periods last longer and there are the signs of EEG "hypersynchronization."

The galvanic skin reaction (GSR) is another conventional method of studying the dynamics of functional states; it is used as an indicator of "vegetative tonus." It has been proven experimentally that there is a direct link between the nature of electrocutaneous responses and change in state of the reticular formation; consequently, they can be considered among the most acceptable criteria of level of general activity. Use of this indicator is related primarily to the task of diagnosing states of emotional tension [stress].

Various parameters of cardiovasculaf function are among the most sensitive and informative indicators of the dynamics of functional states: analysis of main EKG components, heart rate, arterial pressure, circulation ["filling with blood"], perivascular and capillary resistance. The development of stress and fatigue, which is related to increased expenditure of energy, leads to a consistent increase in heart rate, respiratory excursions and other parameters, indicative of intensification of metabolic processes. The typical changes in main EKG parameters for a specific subject could serve as a reliable indicator of the degree of adjustment to a set level of information load.

The dynamics of autonomic somatic parameters--body temperature, digestive and excretory system functions, etc.--are used with success to describe involuntary changes in level of activation during, for example, the circadian cycle.

An extensive area of research deals with the distinctions of hormonal changes under the influence of various work loads and conditions. In spite of the purely technical difficulties involved in using these parameters for diagnostic purposes, the number of methods being developed and already used in practice is constantly growing. Aside from studies of quantitative dynamics of secretion of various hormones as indicators of circadian rhythms, many studies deal with demonstration of distinctions of secretary activity in various behavioral situations, mainly as related to nature and level of work load. Increased levels in blood and urine of a working man of 17-hydroxycorticosteroids or of the "stress hormones," epinephrine and norepinephrine, are generally mentioned as the typical correlates of stress, increased tension and fatigue.

The dynamics of physiological parameters reflect not only general changes in level of body activity, but changes in loads on different functional systems. According to the existing data, analysis of fluctuations of cerebral hemodynamics during the performance of rather complex intellectual work makes it possible to distinguish the main stages of decline in mental fitness and to determine the extent of involvement of various cerebral structures in the process of solving various problems. One observes a typical topography of the points of maximum desynchronization of α-rhythm when solving various problems, according to their content. Fatigue leads to a change in the structural and functional system of electrical activity of the brain, which is also specific for various types of activity. Wide use is made in the studies of load size of its physiological correlates, such as changes in diameter of the pupil and GSR, which permit second-by-second monitoring of the exertion made to perform an assignment (Figure 7).

In view of these data, which are indicative of the systemic nature of the observed changes, it is becoming more important to describe the set of physiological reactions specific to a given state of the body. It is possible to solve this problem adequately on the basis of polyeffector recording of parameters. However, it is extremely difficult to meet this requirement due to the diversity of reactions and dissimilarity of changes observed in the presence of the same state.

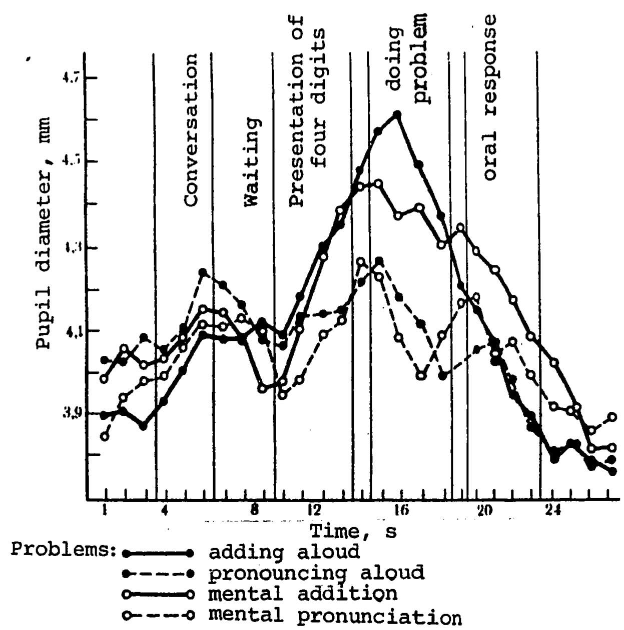

Figure 7. Diameter of pupil as a function of difficulty of task and time required to perform it (after Kanemann, Pivler and Onusku, 1968)

There is no question that a mental load and change in functional capabilities of the body are associated with changes in a number of physiological parameters. Unfortunately, there are many other factors that have an analogous effect on the same parameters. Undesirable properties have been reported [20] in such a popular parameter as the EEG: variability of changes in the same individual, variability of these changes in different individuals, similarity of EEG changes in the presence of substantially different states. It must be stressed that these features are also inherent in other physiological parameters.

The use of physiological indices for diagnostic purposes is also being delayed by substantial difficulties of a metrological nature. In spite of the basic possibility of direct quantitative measurement of changes in physiological functions observed in experiments, the researcher is faced with a number of problems. They include the development and choice of methods of analysis (mathematical models and conceptual analytical schemes) that would be suitable for the material under study. In addition, there are several metrological problems common to all types of physiological measurements, the main ones being problems of standardized levels of function and nonlinearity of measurement scales [57].

The above facts, as well as the methodological flaws in procedures for recording and processing physiological data, usually present real difficulties in using parameters for practical determination of the dynamics of functional states.

Psychological testing methods: Psychological methods of assessing functional states were developed chiefly within the context of studies of fatigue and dynamics of fitness for work. Several main stages are distinguished in the history of development of this problem, and they are related to basically different approaches to formulation of research objectives and evaluation of the diagnostic value of the different parameters [47, 81]. The current stage of research on fatigue began with the publication of the well-known monograph by Bartly and Chute [79]. These authors, who stressed the complex nature of this phenomenon, singled out and submitted to comprehensive analysis three main aspects of the problem. The term "fatigue" was used to refer to a personality-cognitive syndrome combining diverse disorders of mental functions and subjective sensations of fatigue, aversion for work, physical discomfort, etc. Experimental implementation of this approach requires the creation of subjective and psychometric research methods consistent with the purpose of the studies.

A. A. Ukhtomskiy had already mentioned the prospects of using subjective evaluation of fatigue for diagnostic purposes; he wrote that "so-called subjective evaluations are just as objective as any others, and tney offer in practice more delicate and precise criteria of fatigue and fatigability than the existing laboratory methods per se" (quoted in [47]), and this is attributable to the diversity of manifestations of symptoms of fatigue in the individual's internal life, ranging from the set of sensations of fatigue well-known to all to specific changes in self-afferentation that affect the areas of cognition and motivation.

In spite of the widespread opinion that the data referable to subjective experience are of first and foremost significance to discernment of fatigue, for a long time this area of research was neglected. It is only in the last 10-15 years that it began to be studied intensively and fruitfully.

The symptoms of fatigue are quite diverse in the mental life of an individual. Feelings of fatigue, weakness, lack of strength, rapid fatigability and sleepiness are direct manifestations of fatigue. In cases of severe fatigue, one usually observes negatively colored emotional reactions: aversion to work, irritability, hostility, distressing tension, etc. States of physiological discomfort are experienced with varying degrees of awareness: increased perspiration, faster heart rate, appearance of dyspnea, tremor, pain in various parts of the body, etc. In addition, recognized disorders in the area of various mental functions may be included with subjective symptoms. We refer to characteristics of attention (sluggish, static or sporadic, unstable), diverse sensory disorders and disturbances referable to the motor system (change in speed of movement, diminished precision and coordination, deautomation of skills).

We can distinguish two categories of such symptoms: subjective reactions characterized by the individual's attitude toward his own condition, and objectively verified signs of fatigue (physiological discomfort and impairment of mental activity), which the individual may recognize. The existence of qualitatively different groups of symptoms paves a foundation for development of various directions of methods for subjective diagnostics, subjective scaling and questionnaires.

The use of questionnaires is directed toward detection of qualitatively diverse symptoms of fatigue, which could be recognized more or less readily by the individual. Quantitative evaluation or determination of the severity of each symptom is not the main purpose of such studies. Man's state is assessed by the total number of above-mentioned symptoms and their qualitative uniqueness.

Questionnaires differ appreciably from one another in number of symptoms listed and method of grouping them. The number ranges from a few to several dozen or even hundreds. The general trend in developing new questionnaires is the desire to limit the list of symptoms, which conforms with the requirement of brevity of the test description and simplicity of quantitative processing. At the same time, it implies the including in the list of the most important "key" signs.

The choice of the most informative symptoms and groups of symptoms is the chief means of creating more compact and reliable questionnaires. Not infrequently, this work is done on the basis of use of the methods of multifactorial statistical analysis.

As an example, let us consider the questionnaire of physical activity prepared by the Japanese Health Association in 1971. The analytical factor method was used to design the questionnaire. They proceeded from the premise that the entire diversity of manifestations of fatigue could be classified in the following manner: symptoms of low activation, low motivation and physical disintegration, the first two groups of symptoms being common to virtually all types of labor.

Their base material for preparation of the questionnaire consisted of 48 terms describing various manifestations of fatigue. A study was conducted, in which 65 subjects rated the suitability of each term for testing fatigue on a seven-point scale. Two groups of the most informative symptoms, combined under the names of "low activation" and "low motivation,"* were isolated by means of factor analysis, on the basis of the results of preliminary evaluations. We submit below the questionnaire that was developed.

Physical Activity Questionnaire

"Low Activation"	"Low Motivation"
1. Do not want to walk.	1. Mistakes in work.
2. Breaking voice.	2. Avoidance of glance.
3. Not ready to work.	3. Difficulties in communication.
4. Hollow cheeks.	4. Slowness.
5. Avoiding conversations.	5. Sleepiness.
6. Gloomy face.	6. Easily distracted.
7. Lifeless eyes.	7. Pale face.
8. Irritability.	8. Expressionless ["wooden"] face.
9. Apathetic face.	9. Digital tremor.
10. Listlessness.	10. Difficulty in concentration.

Thus, modern studies in the field of developing subjective questionnaires are characterized by a thorough development of the symptoms of fatigue, classification of signs and distinction of decisive factors, development of methods of monitoring [checking] performance of tests. However, there were several serious difficulties encountered in the practical use of existing questionnaires. In the first place, this is related to the lack of developed methods for quantitative evaluation of the obtained results. The total number of symptoms noted is too rough an indicator, particularly if the relative significance of the presence or absence of some sign is not assessed. Moreover, the questionnaires do not usually determine the severity of a symptom. The latter flaw can be overcome by means of methods for scaling a subjective state.

Methods of subjective scaling are designed for the subject himself to assess the degree of fatigue. He is asked to relate his condition to a series of signs, for each of which polar ratings are provided (absence/presence, bad/good). The distance between the extreme points is represented in the form of a multistep scale. The severity of each sign is determined by the location of the point selected by the subject on this scale. Thus, this group of methods is one of the modifications of

*Translator's note: The Russian word for "low" could also mean weak or poor.

Osgood's semantic differential method that is widely used in psychological studies.

The dimensionality of the scales and methods of working with them differ substantially for different authors. As a rule, scales are used that have five, seven or nine gradations. In recent years, ungraduated scales, i.e. the so-called visual analogs of rating scales, are gaining increasing popularity. In this case, the subjects are shown segments of lines of a specified size, on which they have to note the distance that subjectively corresponds to the degree of the rated experience.

The history of use of the scaling method in the field of diagnosing fatigue dates back to the work of Muscio and Poffenberger. They proposed a typical seven-point scale,* which was plotted on the basis of elementary common sense, and it can also be encountered in many current studies.

Use of subjective methods of rating functional states moves to the fore the problem of standardization of the meanings of words and expressions used in plotting a scale or tabulating a list of symptoms. The Thurstone method is generally used for this purpose. The main element for this method is the presence of a large enough group of expert subjects who are working on construction of the scale itself. The first phase of the work consists of selecting a certain number of words and expressions characterizing critical degrees of fatigue out of an extensive list (up to several hundred) verbal characteristics of this state available in a given language. Then, the order of the selected signs on the scale is determined according to the classifications of the same group of experts.

The Poffenberger method is an example of simple, one-factor scaling. When designing scales, modern authors proceed from the conception of existence of a complicated complex of feelings of fatigue. It is assumed that such a set of symptoms is represented by clearly distinguishable groups of signs, the severity of manifestation of which changes in accordance with the degree of fatigue. The test of differentiated self-evaluation of fatigue (SAN)** is an example of a method of multiple factor scaling. In developing this test, it was assumed that it is possible to describe a functional state by means of three categories of signs: state of health, activity and mood [affect]. The subject has to relate his state to a number of signs characterizing each of these categories. The severity of the sign is determined on a seven-point scale.

*I feel: excellent, very good, good, satisfactory, tired, very tired, extremely tired.

**Acronym from the initial letters [in Russian] of the following words: state of health, activity, mood.

The SAN test consists of a card on which there are 30 pairs of words with polar meanings. Each of the three categories is characterized by 10 pairs of words. In the "state of health" category there are the characteristics of strength, health and fatigability, for example: state of health--poor/good, I feel strong/weak, full of energy/without energy, etc. In the "activity" category there are the characteristics of mobility and rates of various functions: passive/active, immobile/mobile, slow/fast, etc. Characteristics of the emotional state are included in the "mood" category: cheerful/sad, bad/good mood, joyous/gloomy, etc. Presentation of polar signs referable to the same group 10 times increases the reliability of the data obtained. The location of positive (negative) signs on both the right and left sides of the card reduces the possibility of deliberate distortion of the results.

The data for each category of signs are averaged, and three quantitative parameters are to be used: arithmetic mean, standard deviation [mean-square deviation] and arithmetic mean error. The arithmetic mean is the direct characteristic of degree of fatigue, while the scatter of ratings within a group of signs (standard deviation) serves to judge the degree of reliability of the obtained results and, accordingly, reliability of testing.

According to the data of the authors of this method, its use permits a description of a functional state not only according to absolute ratings of state of health, activity and mood, which diminish as fatigue develops, but also according to the indices of correlation between them (Figure 8). In a rested person, all three categories of signs are given similar grades. As fatigue increases the divergence grows as a result of decline of indices for the state of health and activity, as compared to subjective rating of mood.

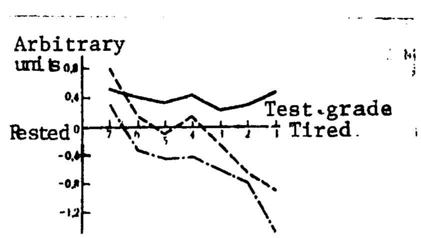

Figure 8.
Mean divergence between SAN test categories with different degrees of fatigue (after Doskin et al., 1973)
——) difference between state of health and activity
----) difference between state of health and mood
-·-·) difference between activity and mood

Methods of subjective rating of the functional state are developing along the line of creating complex and multiplane tests based on the use of modern mathematics and assimilation of data accumulated in the area of traditional use of the scaling method in subjective psychophysics. However, it would be wrong to believe that development of this direction of research is encountering only metrological difficulties.

Already in the first experimental studies of fatigue it was noted that the feeling of fatigue could be the result of low motivation, lack of interest in performing the work, and that a change in activity restored the initial fitness level. Subjective ratings of fatigue also depend on factors that are extraneous to the operational structure of activity, such as level of pretentions and degree of imposed responsibility. In addition, subjective ratings are overtly or indirectly related to evaluation of the difficulty of the activity performed. This circumstance is related to the problem of consistency between the subjective ratings of difficulty of activity performed. For this reason, identification of functional states solely on the basis of subjective experience and self-evaluation may be far from reflecting the true state of affairs.

In psychological practice, diagnostics of functional states are most often made on the basis of analysis of efficiency [effectiveness] of performing a certain type of activity. Analysis is made of the dynamics of indices of quantity, quality and speed of performance, as well as changes in the corresponding psychological functions upon which performance is based.

The objective of analysis could be to describe the indices of performance of actual work. The main indices of dynamics of fitness in this case are the characteristics of total amount of production, number of disruptions and changes in work pace as related to duration of the work day and influence of diverse deleterious environmental factors, such as poor organization of the production process, insufficient light at the work place and ventilation of rooms, deleterious factors related to the specifics of production.

However, the dynamics of labor productivity depend on many diverse causes, a significant part of which has no direct bearing on changes in the functional state of a working man. Moreover, for a large number of occupations, this parameter cannot be submitted to quantitative consideration at all, although the task of determining states is also an important one for them. For this reason, the main psychological means of so doing is to use short tests which rate the dynamics of various mental processes while performing a work assignment. In this case, the problem of evaluating a functional state emerges as a typical psychometric problem: to describe and quantitatively rate the changes in psychological characteristics under study that occurred under the influence of certain causes (in our case, work).

We should include among the traditionally used procedures the tests for determination of absolute and differential sensitivity thresholds in various modalities, indices of visual fitness, critical flicker fusion frequency and critical phosphene fusion frequency, analysis of dynamics of successive patterns. However, the changes observed in these physiological parameters are most often erroneously referred to the group of physiological tests.

A change in functional state from the standpoint of the sensorium is manifested primarily by changes in sensitivity. Already in the early studies of fatigue, it was found that there was a decline of tactile and auditory sensitivity with fatigue. A decline of visual sensitivity is observed under the influence of the most diverse factors--diverse deleterious exogenous environmental factors (Figure 9), when performing work for a long time, with loads of varying intensity, etc. The CFFF (critical flicker fusion frequency) test is considered to be one of the most popular and reliable methods of detecting this. In the presence of fatigue and exposure to diverse stressors, one observes an appreciable decline of this parameter, i.e., decline of visual time resolution capacity. This is indirect evidence of increased inertia of processes in the visual system under such conditions.

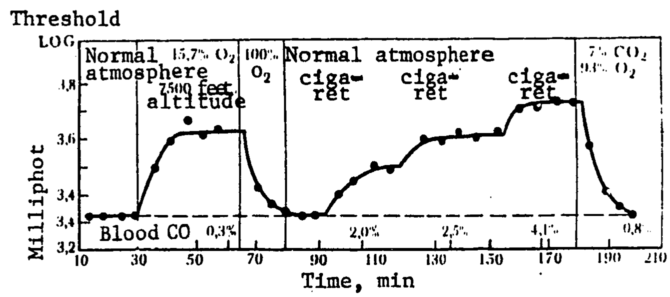

Figure 9. Influence of altitude, smoking and air oxygen content on sensitivity of the eyes to light (after MacFarland, 1946)

Analysis of the dynamics of various manifestations of motor activity of man is referable to another group of psychometric methods, which cannot always be clearly differentiated from physiological recording methods. Along with a strong physiological basis for the study of these characteristics (first of all, this refers to the vast area of myographic studies), there are diverse psychological methods of analysis. Different variants of the step test and tapping test are traditional means of diagnosing functional states.

Wide use is made of diverse methods of evaluating different mental functions: perception, memory, attention, thinking. Most such psychometric methods began to be developed at the first stage of research on the problem of fatigue, at the end of the 19th century. They include the well-known Bourdon test, the Kraepelin method of continuous counting of single-digit numbers, the Pierre-Ruzere elementary coding method, the method of testing attention using the Schulte tables, etc. [53]. Numerous modifications of these tests are still used extensively in psychological practice.

The use of psychometric methods is one of the most promising means of solving the problem of determination of functional states since, on the one hand, they directly describe the functional capabilities of man and, on the other hand, they are objective in the sense that they rule out the possibility of deliberate overestimation of fitness. However, most of the existing methods have two serious flaws.

First of all, the assignments used to determine a functional state have little in common with activities that man actually performs. Today there is validity, as there was decades ago, to the comment of A. P. Nechayev that these techniques "make it possible to record changes that take place in the realm of only a specific aspect of mental life, and the results obtained by one method cannot always be interpreted as indications of fatigue" [53, p 16]. The lack of consistency between testing methods and work activity leads, in many cases, to failure in testing functional states in real situations. We can site the results of one study [see 81] as a vivid example of this inconsistency between a test and the task of diagnosing fatigue. After continuous work for 56 hours on a conveyer, the subjects failed to demonstrate an appreciable decrease in efficiency of performing a psychometric test. This could hardly be attributed to motivational effects; in this case, we would have to speak of the subject's heroic effort. Most likely this is indicative of the inadequacy of the chosen testing procedure and insensitivity of the parameters analyzed.

The suitability of a test for a specific diagnostic problem is determined by the central concepts of theory of psychological testing: validity and reliability [25]. Depending on the purpose of a study, the content of these concepts can be considered on different levels: from the standpoint of their theoretical significance, set of statistical procedures for quantitative description, etc. In the most general sense, validity reflects the conformity of the chosen method with the research problem, while the concept of reliability is used to determine the stability or reproducibility of obtained evaluations. Meeting the requirements of validity and reliability implies that there is an adequate theoretical conception in the spirit of which the test is developed and problems of standardizing the selected procedure are solved. Fulfilment of these requirements renders the work dealing with development of effective diagnostic tests extremely difficult and labor-consuming.

Another basic flaw of the existing psychometric testing methods is that they can merely evaluate activity in the aspect of its results and, as a rule, say nothing about the causes of the observed changes. Yet it is a known fact that work loads lead primarily to mobilization of the body's resources and change in work methods without changes in its results [58]. For this reason, it is imperative, for effective testing, to use a system of functional tests that determine the state of all elements of the operational structure of the form of mental activity under study.

An effort was made to find an experimental solution to the problem of the effect of fatigue on information processing in short-term memory using a system of functional tests that assess the efficiency of performance of various operations in the microstructure of short-term memory [40]. For this purpose, a computer-automated system of tests was developed, including typical procedures for examining the information-processing process: time of recognition reaction, complete reproduction, retrieval signal in the presence of interference, identification of missing number. The success of using the different methods is determined by the efficiency of performance of certain psychological operations or groups of operations that are specific for solving concrete problems.

The proposed system of tests as a whole was found to be suitable for use for diagnostic purposes. Under the influence of a load there is substantial decrease in efficiency (from the standpoint of correctness and speed of performance) of performance of most tasks considered. The typical signs of dynamics of fitness during a lengthy process of activity can be readily tracked according to the indices of performance by the methods in question [40]. In the course of the study, the methods that were most sensitive to the influence of fatigue were selected; they include the method of retrieving a signal in the presence of interference, recognition, complete reproduction and determination of a missing number. For each of them, the range of conditions was found, under which there is maximum expression of the effect of a load.

It was established that fatigue selectively affects performance of the same operations, distinctive "weak points" in the system of information processing. These effects include increased duration of information storage in sensory memory, impairment of operations of repetition and retrieval of information from primary memory, impairment of operations of establishing semantic associations in secondary memory. The duration of information storage in primary memory, as well as operations of sensory processing of a single stimulus, recognition thereof, transfer to primary memory and response, remain relatively unchanged.

The substantial advantage of this system of tests for short-term memory is that it is automated on the basis of computers. Use of computers on the experimentation line broadens significantly the possibility of using diagnostic methods. The quality of psychological testing is substantially improved by complete automation of the main stages of an experiment, significant expansion of the range of experimental conditions used (qualitative diversity and unlimited amount of stimulus material, rather broad range of variation of modes of presenting information, etc.), possibility of using optimum strategies for conducting the study on the basis of adequate mathematical procedures for planning the experiment and developing programs of the adaptive type. In addition, the use of computer technology makes it possible to process data on the real time scale, which provides an immediate evaluation of a man's functional state.

However, it is not always possible to introduce computers into the area of practical studies of functional states. In this case, "small-scale automation" is helpful, i.e., portable devices specially developed for testing by means of a narrow class of psychometric problems within a preset limited range of experimental conditions, that are small in size, convenient to use and portable.

Complex methods of evaluating functional states: Our analysis has shown that substantial flaws are inherent in all existing methodological directions of assessing functional states. This problem can be solved only by means of using complex methods combining the advantages of the different approaches discussed. This is the logical conclusion derived from interpretation of a functional state as an integral characteristic of existing properties and traits of man, which determine the efficiency of his performance.

It is unlikely that we could find in the current literature any experimental work, in which evaluation of the dynamics of a functional state of man was made with the use of only one methodological procedure. Even in cases where the purpose of the study is to analyze the dynamics of some special sign, investigators always relate the results to efficiency of performance of a behavioral problem put to an individual, to data pertaining to his subjective feelings, etc.

Proof of the need for integral description of functional states of man, as well as the possible routes of implementing this principle, were considered more comprehensively within the framework of analysis of the main methodological approaches to the problem of diagnosing functional states. Solving this problem for physiological research is related to development of adequate polyeffector recording methods. But development of psychological testing methods is proceeding along the lines of developing multiplane subjective tests and various psychometric tests. This is a mandatory but still far from completed preliminary stage of work. The next step on the road toward solving the problem of diagnosing functional states is the conduct correlation studies and, on their basis, to develop complex systems of tests of a higher order.

The focal problem in this direction of research is to select, out of the enormous number of existing methods and means, the most reliable and convenient ones for practical use. The requirement of practical suitability can be met, in principle, by any method by improving the testing procedure, methods of recording and processing data on the basis of using modern technology (use of computers in the experiment line, development of portable units, use of adequate mathematical models and methods of statistical analysis). The reliability of the selected methods is determined by the sensitivity of the parameters used and their conformity with specific testing tasks and conditions.

With reference to the suitability of some type of parameter of dynamics of functional states, the problem of sensitivity of the criteria used is advanced to the fore. It is important to stress that dissimilar dynamics in time are inherent in various manifestations of changes that occur in the functional state of the body. This well-known fact is drawing more and more attention on the part of researchers. In one of the experiments, a study was made of the change in efficiency of performing arithmetic problems, symptoms of subjective stress, dynamics of heart rate and secretion of catecholamines during prolonged exposure to noise. The results of this experimented demonstrated not only the existence of typical dynamics of different parameters in the presence of noise stress (on the order of the adaptation reaction to excessive loads), but the qualitative uniqueness of manifestations of deferred effects of stress. Thus, while the subjective feeling of discomfort does not last long and has a tendency to disappear soon, endocrine activity is quite lengthy (from several hours to 2 days) and increases after termination of stimulation. Behavioral and physiological changes are observed both during exposure to a stressor and for a certain time after discontinuing the noise.

From this vantage point, the problem of sensitivity of methods acquires a different coloration: the screening of diagnostic parameters must be made with due consideration of the time interval between exposure to a load and moment of appearance of maximum changes in the area analyzed.

Another, more important aspect of the problem of choosing the most sensitive methods is their consistency to specific types of work activity. The diagnostic problem is always strictly defined. Investigators are compelled to study certain types of functional states that arise when an individual has to solve specific behavioral problems. Different types of work activity make strictly specific demands of man, with respect to their content (occupational characteristic) and specific working conditions. The load on various elements of the system that provide for the performance of a specific type of activity is far from the same. But since the efficiency of the system as a whole is determined by the state of the elements that experience the greatest load or bear the most responsibility for success of the work, the corresponding methods of studying efficiency should address themselves primarily to these elements. A series of experimental studies showed that tests chosen on the basis of analysis of the functional structure of activity are diagnostically more informative than the standard "universal" methods. Thus, comprehensive psychophysiological analysis of specific types of work activity is a mandatory prerequisite for developing complex systems of tests suitable for evaluating the dynamics of functional states under actual production conditions.

6. Modeling in Ergonomics

Modeling of the structure and functions of man-machine systems has become very popular in ergonomics. There are different types of modeling:

objective [in the sense of dealing with an object], objective-mathematical, symbolic and its most important form, mathematical. In addition, wide use is made of stochastic modeling, which is based on establishing the probabilistic relations between events.

Objective modeling, in the course of which the study is conducted on a model that reproduces the main geometric, physical, dynamic and functional characteristics of the "original," is a typical distinction of many ergonomic studies [11].

Static and functional models are used [50]. The former are usually three-dimensional, real-scale models of equipment, different units thereof, that are tested. A static model can be used for the following purposes: choice of optimum means of arranging equipment; ergonomic evaluation of equipment and answering questions about its operation that cannot be answered by means of two-dimensional blueprints; solving problems of arrangement of the work place; testing arrangement of controls from the standpoint of convenience of handling; checking accuracy and speed of instrument readings; determining accessibility of check points, testing and adjustment points in the course of technical maintenance of equipment.

A functional model is a model of equipment on a real scale and, unlike the static model, it can reproduce the actual operation of equipment in manual and automatic control settings. Simulators intended for training of specialists and used to study and solve problems of planning [design] of the corresponding type of activity can be classified as this type of model. The functional models used in ergonomics are experimental models of the man-machine system or its subsystem, constructed in accordance with certain rules, the properties of which determine man's performance in such a manner that its main characteristics correspond to the parameters of performance in a real system [76]. There can be significant expansion of the use of functional models in ergonomics with the use of electronic and computer technology as programming and analytical devices.

A functional model can be used to study the work activity of a man (or group of people) under simulated working conditions in order to compare alternative variants of design (or to check the only chosen one), as well as to evaluate the different features of equipment. Thus, a 1:1 scale prototype of a lathe and special stand, which permits ongoing reproduction of spatial conditions of lathe operator work, were developed to check draft proposals and provide ergonomic substantiation for artistic designs of hydraulic copying lathe with programmed control. A series of three-dimensional models of the lathe and work zone is successively reproduced on the stand by means of sliding metal rods and detachable ["suspended"?] equipment simulating the main working elements of the lathe (clamping chuck, tailstock, etc.). Bioelectrical activity of muscles was recorded while subjects worked with a specific model. The obtained myograms made it possible to select one out of several tested variants, the dimensions and geometric shape of which caused minimal muscular tension in the lathe operator to maintain the working pose [36].

There is an acute need in ergonomics to use mathematical modeling methods. More recently, large amounts of models of human factors have appeared in engineering. However, by far not each of them does indeed simulate the process under study, and not infrequently modeling is transformed into a game with mathematical symbols. Nevertheless, this does not warrant questioning the fact that the desire to provide a mathematical description for human factors as a whole is unquestionably instrumental in development of ergonomic theory and practice. The main problems that arise are related to demonstration of the entire set of psychophysiological properties and traits of man that are essential to his activity in the system. Expressly these must be reflected in the corresponding mathematical models that are called upon to provide a quantitative description of this activity [64].

Methods have been developed, in which such characteristics are submitted to quantitative modeling as quality of operator performance, competence and professsional performance of operators, their psychological orientation ("personal," "collectivistic," "business-like"), mental tension (stress), morale and solidarity of the group and others [35, 37]. Work is being conducted to systematize models intended for description of human performance in concrete modes of operation of the man-machine system [6].

The use of simulator models in ergonomic and engineering psychological research of man-machine systems is related primarily to the desire to cover in one description both man and the technical components of the system, the need to describe processes of man-machine system function in a generalized form that would permit distinction and study of subsystems and relations between them, as well as the desire to be rid of detailed descriptions of intrasystem processes [32]. One of the most promising directions of development of modeling for the purpose of planning human activity is the use of the theoretical and mathematical system of game theory [31]. Ergonomics needs mathematical methods for planning and processing experimental data. Planning an experiment, which refers primarily to the system of conceptions of rational strategy of a concrete study [44], is an important condition for effective development of ergonomics as an area of scientific and practical endeavor.

7. Use of Computers in Ergonomic Research

Construction of adequate models of man's activity requires consideration of an ever increasing number of factors and correlations between them, which leads to constant complication of models and methods of working with them. It is important that such models consist of either "poor" equations, which cannot be solved analytically, or systems of a large number of equations or, finally, logically complex constructions with a large number of connections and conditions. In most case, it is basically impossible to work with such models without using computer technology.

The every-day requirements of practice stimulate even more the penetration of computers into the area of concrete research. Among such problems, we can mention the need to obtain a sufficient amount of experimental results within a relatively short time, development of a system (bank) of standard reference data in ergonomics, extrapolation of results obtained from laboratory studies to real working conditions, to obtain the quantitative characteristics of man's capabilities when performing different types of cognitive and productive [executor] activity.

Such problems can be solved effectively only on the basis of total and partial automation of diverse ergonomic studies. It is only on this route that it is possible to change to "industrialization" and standardization of investigative methods with wide use of quantitative ratings which, in turn, would permit increasing the reliability and comparability of results of different studies.

Processing of experimental results (surveys, questionnaires, behavioral parameters, physiological parameters, etc.) is the most accessible (and popular) form of using computers. The use of computers is attributable to its capacity to work with large arrays of data at a speed that is greater by several orders of magnitude than human capabilities. In addition, computer processing makes it possible to use more powerful equipment for analysis of experimental results than any that is available for "manual" processing. Suffice it to mention as an example the many types of multidimensional analysis (special correlation, multiple regression, etc.).

Until recently, experimental studies were conducted in two stages: first the experiment proper (information gathering), then analysis and processing of the information obtained. Computers were used primarily at the second stage. There are examples of automation of only the first stage, direct conduct of an experiment, for example, to present information within a specific time following a strict program prepared before the experiment.

However, in many cases, such a two-stage procedure is extremely ineffective, since the lack of coordination in gathering data in the course of the experiment leads to storage and processing of a large amount of superfluous information. Moreover, the surplus of "raw material" makes it difficult and sometimes impossible to single out the sought patterns. One way to overcome these difficulties is to conducted automated experiments, in which the computer monitors the progress of the experiment, processing data as they are received (on a real time scale) and selects the required strategy for running the experiment. Such use of computers appears to be the most efficient. It is then possible not only to make an ongoing study of numerous characteristics in the course of one examination, but to conduct experiments that are basically unfeasible with the use of any other technical base, since the need arises in such experiments to make decisions according to some rather complex algorithms within periods measured in milliseconds.

Thus, various tasks are put to computer technology in modern experimental research: data gathering, data processing, control of large complexes of devices with adherence to rather strict schedules and, finally, implementation of adaptive and even self-optimizing controlled experiments. However, there are many difficulties in the way of effective use of computer technology in ergonomics and allied scientiifc disciplines. We can mention such circumstances as the need for the researcher to acquire skill in solving many problems that are not customary for him. In particular, there are the problems of inputting data in the computer, eliminating superfluous material, excluding artefacts, convenient method of presenting the final results of processing, programming, etc., for each computer with its own technical features.

The diversity of existing computers, which are being manufactured or designed, also creates the difficult problem of selection of the type of computer. The exceptionally rapid development of computer technology, frequent change in types and generations of computers, their software and programming languages lead to a situation that, from the standpoint of the consumer, the computers may become obsolete after barely starting to be used.

However, the focal problem that will determine the efficiency of using computer technology in ergonomics is primarily that of formulating specific problems to be solved with computers. The widespread opinion that "machines can do everything" is not always by far associated with awareness of the fact that it would be futile to use a computer without a properly formulated problem. After all, computers do not simply "calculate rapidly." Virtually any attempt at using them is primarily limited by the extent of our ignorance. The task for a computer cannot be simply to study a certain phenomenon. There is the mandatory stage of preparing the proper algorithm for solving a problem in all its details. It happens that the need for the experiment proper no longer exists as a result of such preparatory work. The success in solving some problem or other depends on the level of expounded hypotheses and refinement of models to a much larger extent than on the use of modern technology per se. And this work is still the prerogative of man, at least fore the foreseeable future.

At the present time, more or less traditional mathematical methods borrowed from engineering sciences are used in ergonomics in the transition to analysis of data with computers: information, signal processing, operation testing, pattern recognition theories, etc. But when setting up a specific experiment, it is sometimes necessary to either modify these traditional methods as related to the problem to be solved, or to develop new methods and algorithms.

The hardware used in ergonomic research also (with rare exceptions) consists of standard devices and instruments that are not specially designed for use in this field. For this reason, as a rule it is necessary to make some effort to adapt this hardware to the conditions of an ergonomic experiment proper.

It should also be noted that the use of computers makes it necessary to basically alter the entire structure of an experiment. At the same time, planning the experiment, extent of modification of experimental procedures and the equipment involved depend on the means of using a computer. As an example, we can mention here some of the problems that arise when a computer is used in a nonindependent mode (on the line of the experiment): alienation of the experimenter from direct participation in the experiment requires the use of complex and diverse procedures for regular checking of all equipment; for the same reason, the instructions to subjects have to be basically changed; it is impossible with given technical features of a computer to evaluate on a real time scale some of the traditionally used parameters, which may make it necessary to study other characteristics, etc.

However, it should be borne in mind that the most thorough formulation of problems and proper use of mathematical methods does not guarantee immediate success and does not prevent the disappointment of those who expect too much from "computerization" of studies. And this may not be a matter of particular mistakes and oversight on the part of the investigator or flaw in the computer or methods used; it could be the consequence of wrong choice of approaches to analysis of ergonomic problems which were generated in studies of physical systems that are immeasurably simpler than the phenomena mentioned. It may be that, in principle, the existing algorithmic methods are not applicable for interpretation of data of ergonomic and psychophysiological studies. An analogy is suggested here to the problems encountered by researchers involved in computer translations. Their solution generated a radical change in views about the structure of language and, furthermore, about formulation of the problem itself. Thus, in analysis of human factors, psychological phenomena and "languages of the brain," it will perhaps be necessary, in time, to alter substantially the existing approaches [48].

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CHAPTER IV. PRINCIPLES IN ERGONOMIC ANALYSIS OF WORK ACTIVITY

The category of activity is the most important in the system of developing ergonomic science. Labor is performed in various forms of objective [object-related] practical, industrial, cognitive and control activity. "Activity is a specifically human form of attitude toward the world around man, the content of which is purposeful change and transformation of this world" [62, p 267-268]. To man, the objects in nature lose inherent purpose and emerge as objects, i.e., primarily as the means of making tools. The use of work tools implies that there is a set goal that man is governed by as the ideal image of the required product. K. Marx described this basic distinction of work activity in the following manner: "At the end of a work process a result is obtained that was already in man's mind at the start of this process, i.e., the ideal. Man not only alters the form of what was given by nature; at the same time he achieves his conscious goal through what was given by nature, and like a law it determines the means and nature of actions, and man must subordinate his will to this goal" [1, p 189]. This quote clearly indicates the main structural elements of work activity: goal as the ideal conception of the result, method or means of reaching it and, finally, will, i.e., specific meaningful personality-related elements.

In ergonomics, activity emerges as the subject of objective scientific study. It is broken down and reproduced in theoretical schemes and models, in accordance with the methodological principles developed in science, and in accordance with specific ergonomic tasks. In ergonomics, activity also emerges as the object of control., i.e., that which must be organized into a well-adjusted system of operation and (or) development on the basis of the aggregate of fixed principles that must be formulated in ergonomics, social psychology and industrial sociology. In ergonomics, activity emerges also as the object of planning [design], i.e., ergonomics is faced with the task of demonstrating the methods and conditions for optimum implementation of certain (chiefly new) types of work (and professional-educational) activity. Finally, in ergonomics activity also emerges as the object of multilevel evaluation, which must be made in accordance with various criteria, such as efficiency, reliability, satisfaction with work, comfort, etc. Thus, activity emerges in ergonomics as the beginning, content and end of ergonomic analysis, organization, planning and evaluation. Of course, this very general description of functions of activity can only play the role of a methodological guideline for ergonomic research. In order to solve scientific and practical problems of ergonomics, a certain constructive meaning must be imparted to the concept of activity. This is by no means a simple task, since conceptual schemes of analysis of activity have not yet been sufficiently developed in ergonomics. For this reason, wide use is made in ergonomics of the conceptual schemes for analysis of work activity that exist in allied disciplines, particularly psychology and sociology. These conceptual schemes are not only assimilated by ergonomics, but transformed in accordance with the specifics of the problems it has to solve. Ergonomics is compelled to develop analytical methods and demonstrate the functional structures of various types of work activity, ranging from relatively elementary ones to those of utmost complexity, which were generated by the scientific and technological revolution. This is the mandatory prerequisite for optimization of work activity, rational planning of new types and forms thereof. Otherwise, such problems are solved either on the basis of common sense, or empirical examination of many factors which have some influence or other on efficiency and other aspects of work activity, i.e., by the method of successive approximations.

Before we describe the functional structure of work activity, units of analysis thereof and types of relations between them, we must describe the main types of work activity.

1. Classification of Working Occupations

In the historical aspect, a distinction is made between three main stages of development of technology and labor or the "technology--man" system: manual labor, mechanized labor, automated labor. All three types of labor exist in modern industry. Ergonomics, having emerged at the stage of automated labor, nevertheless is related to all three types thereof. Ergonomics needs an orderly classification of modern types of labor. At the present stage, it is deemed expedient to use the classification developed at the USSR Central Statistical Administration for grouping workers (occupations) according to the factor [tag] of mechanization of labor to compile a list of workers according to occupation. Such separation of workers into groups according to mechanization of labor was used with success in sociological analysis of labor problems [59]. According to this classification, there are five groups of workers differing in degree of mechanization of labor activity.

The first group refers to workers who use automated machines, apparatus and installations. This includes workers who monitor the operation of automatic and semiautomatic units, parts, apparatus, lathes, etc., regulate the mode of their operation, adjust and fix them. This group also includes workers with semiautomatic machines, lathes and apparatus if their duties are also to monitor and regulate the operation of the semiautomatic machines, as well as repairmen and adjusters of semiautomatic machines whose function is mainly observation.

The second group refers to those who work by means of machines, lathes, devices, apparatus and mechanized instruments (lathe operators, machine operators, drivers, tractor operators, instrument control workers, motor mechanics, pick-hammer operators, gas and electric welders, etc.). Direct control of a machine or apparatus is inherent primarily in all these workers. Within this group, a separation is sometimes made into subgroups, depending on the sophistication of work tools used.

The third group refers to those working manually with machines and devices who supplement with their manual labor the operation of the machines (shop hands): loaders of containers and transporters; sorters, packagers, wrappers, washers, dispensers and other workers enaged near machines and devices. This group of workers can perform utterly analogous work to an equal extent involving both nonautomatic machines, automatic and semiautomatic ones. Unskilled and usually monotonous labor is inherent in this entire group.

The fourth group refers to workers engaged in manual labor or who use unmechanized tools, not in contact with machines and devices, i.e., purely manual labor (unskilled labor of the manufacturing type, highly skilled workers of the craft type, highly skilled labor involving manual complex assembly and adjustment of intricately assembled products.

The fifth group refers to workers who overhaul machines and devices, locksmiths [fitters, mechanics], electrical fitters, electrical assemblers and repairmen, including attendants. This group also includes repairmen, adjusters of lathes and machines, instrument installers whose main function is adjustment [trouble shooting].

At the same time, workers in repair groups, sections, shops, factories and plants who are not involved in complex machinery overhaul but specialized operations, can be referred to any of the first four groups. For example, lathe hands and other lathe operators, gas and electric welders involved in repair work are classified in the second group as workers who perform their work with the help of machines and mechanized tools.

In this classification, there is overlapping of jobs involving manual, machine and automated production. Critical comments have been voiced about the strictness of classification in the third and fourth groups, which include both unskilled (shop hands, riggers, loaders, etc.) and highly skilled (fitters, electrical assemblers, fitter-tool makers, etc.) manual laborers. Nevertheless, a better classification of types of work activity has not yet been devised.

For the purposes of ergonomic analysis, the occupations are broken down even more in most cases. Thus, workers involved with automated control systems, or operators (first group) are subdivided into five types, in accordance with which there are five classes of operator activity.

1. Operator-technologist. The operator is directly involved in the technological process; he works chiefly in the mode of immediate servicing, performing primarily actuating [executory] actions governed by instructions that strictly regulate the actions, which usually contain a complete set of situations and decisions. These are operators of technological processes, automatic lines, operators who perform the functions of formal recoding and transmission of information.

2. Operator-manipulator [keyer]. In this case the main role is played for operator by mechanisms of sensorimotor activity, as well as figurative and conceptual thinking, though to a lesser extent. Among the functions of an operator-manipulator are the control of manipulators [keys], robots, machines that amplify muscular energy. The same category includes operators that service radar stations, which is a classical object of research in engineering psychology. True, the activity of these operators could be referred with equal justification to the next type, the activity of an operator-observer, since an enormous share of the load in performing tracking functions, monitoring targets against the background of interference, is also borne by the visual system.

3. Operator-observer, controller [monitor]. This is the classical type of operator (operator for tracking at a radar station, transport system dispatcher, etc.). This type of activity is characterized by the large "weight" of information and conceptual models; accordingly control skills are somewhat reduced (as compared to the first two types of operator activity). He can work in both the mode of immediate and deferred servicing. This is the predominant type of activity for operators of engineering [technological] systems operating on a real time scale.

4. Operator-researcher [investigator]. Such an operator makes considerably more use of conceptual thinking and experience contained in graphic-conceptual models. Control elements play an even smaller part for him, while the "weight" of information models, on the contrary, is substantially increased. Such operators include researchers of any field: computer system users, object (image) decoders, etc.

5. Operator-administrator. He does not manage the technological components of systems or machines, but other people. This management is done either directly or indirectly, through technical equipment and communication channels. Such operators include organizers, administrators on different levels, individuals who make important decisions, who have the appropriate knowledge, experience, tact, will power, skill in decision

making and intuition. Operator-administrators must work, not only with an object, they must consider not only the capabilities and limitations of the machine components of a system, but take full consideration of the distinctions of their subordinates, their capabilities and limitations, condition and mood. Dynamic [operational] thinking is the main mode of activity of the operator-administrator.

With all its flaws, this classification of operator activity clears the way for coordination of exogenous ways and means of activity and it permits, at least at the start, better orientation of research and practical work in ergonomics [39].

The area of ergonomic research covers primarily the types of work activity that are related to the use of equipment [technical means]. Work that is done by hand is sometimes included in the area studied by ergonomics; there are several ergonomic publications dealing with problems of manual labor.

Thus far, a universal classification of equipment has not been developed, which makes it difficult to develop its ergonomic classification, a need for which is being felt more and more acutely because of the necessity of preparing ergonomic specifications and recommendations for specific types of equipment. The following are objects of ergonomics: industrial equipment (machines, machinery, instruments, apparatus for the control of machines and technological processes, transport, communications, etc.); nonindustrial equipment (equipment for municipal and household services [utilities],* as well as military equipment (tackets, rocket installations, aircraft, ships and submarines, etc.).

For purposes of preliminary analysis, of interest is the general classification of tools and means of labor according to degree of their automation [43], which permits schematic presentation of the main objects of ergonomic analysis:

*It was indicated above that cultural and everyday products, as well as household products have already become the object of ergonomic research. In order to evaluate them properly and design the consumer properties of such products, their use should also be considered as a special form of activity, as consumer activity. The similarity of dynamic and technical components of work activity and consumer activity should not lead into error. Their goals, motivation and results are basically diffeerent, as are the requirements concerning the conditions for their use and degree of comfort. Consumer activity has yet to become the subject of a special investigation.

a) manual tool and most elementary device
b) mechanized and electric-powered tool
c) machines without compulsory connection of operating element with object of labor, which operate when the worker that services them is working
d) isolated semiautomatic machines, in which there is compulsory connection of operating element with the object of labor, but without automatic loading and unloading of materials and products
e) isolated automatic machines, in which there is automation of all processes in the work cycle, supplying materials and putting out ready products
f) semiautomatic units (combines, assemblies), in which all processes are automated, with the exception of loading material and unloading ready products, usually consisting of a combination of various mechanical devices (for example, lathe and transmission mechanism)
g) automated units, in which all processes are automated including maintaining a set mode and methods of inputing control programs

The ergonomic classification of types of work activity does not coincide with either the classification of types of work, classification of occupations or classification of work tools, i.e., external means of work activity. The classification of means (methods) proper of work activity should serve as its main foundation. Thus far, such a classification has not been developed, since conceptions of internal means of activity have not yet been sufficiently analyzed in either ergonomics or psychology. For this reason, at the present stage of development of ergonomics we have to limit ourselves to a general description of work activity involving different means of labor, paying attention to the most important psychological distinctions of these processes.

One can distinguish cognitive, executory and motivational, including goal-oriented, aspects, in any labor, as in any other activity (learning, playing). Of course, the content of each of these aspects, as well as the correlation between them, is specifically historical. They are determined by the development of goals, refinement of means of production, technological modes and conditions of labor. This is demonstrable with particular distinction when we compare the psychological features of work activity to such production means as a tool, mechanized systems or machines and automated systems.

The most interaction between a subject and object of labor occurs when using tools or various types of instruments. Not only the labor of the fitter-tool maker, builder or specialist in repair or overhaul, work of a physician and designer, but unquestionably also workers in some types of art, applied art, sculptors, etc., are examples of these types of activity. In these cases, the object stands before the subject in all the diversity of its properties, while the subject has diverse possibilities of altering and using them to obtain the desired result. In order to take advantage of these possibilities, he must perform not only executory, but various analytical and cognitive actions; in other words, he most solve the problem by means of most efficient organization of his actions. In this case, the means of production itself--tool instrument as it is conceived or designed--reflects both the properties of the object (shape, composition, etc.) and the functional distinctions of man's mode of action with the object, the effort he must apply, precision required and speed of action. Many tools and instruments developed long ago still amaze us with their "wisdom," convenience and simplicity of use, but chiefly with the possibility of developing new forms of objects or transforming the same object in an utterly different manner, with qualitatively rather than only quantitatively different results, by using them. The immediacy of interaction with the object by means of object-specific and function-specific means of work activity creates conditions, not only for executory but cognitive actions. There may be different correlations between them in similar work processes, which is determined primarily by the requirements as to the results of these actions, rather than the object and means of work actions. The requirements referable to the functional or, for example, aesthetic qualities of the result determine the method of work actions and efficiency of their performance. When he makes use of tools, man applies his capabilities, acquires experience and skills in different areas of work activity. He also satisfies his need to learn and create. This type of work is characterized by development of new, more convenient or purposeful means of production, of obtaining new results.

Activity proceeds differently when using mechanized means of production in the man-machine system. Here, the object of labor (or base material, stock, etc.) emerges only with a limited number of properties, since a machine is incapable of considering all of the properties of material. The poorer qualitative content of interaction with the object is also associated with greater requirements concerning the quantitative characteristics of interaction, for example its speed or amount of energy expended. Accordingly, requirements are made under these conditions for the work actions of man, from the standpoint of a specific quantitative effect, i.e., obtaining a specified volume of production within a minimal time and with the least expenditures.

Under these conditions of work activity, it becomes a constant need to increase accuracy, organization and stereotypism of executory actions. As a result, there is virtually no "room" left in the work act for cognitive action. Production itself does not require and even does not permit any deviations whatsoever in the qualitative characteristics of the result in relation to what is specified. It requires that man apply only a limited range of his capabilities, chiefly certain skills and efficient coordination thereof with the time schedule of machine operation. In essence, not only the object of production, but the machine itself becomes the object of work actions for man. It is expressly to its spatial and time distinctions that he has to adjust his actions.

Accordingly, man's initiative in optimizing work activity may be manifested chiefly in the area of organizing this activity, development of a professional style, refinement of technology, i.e., all that pertains to the means of action, rather than means of production and properties of the object. Mainly individuals in other specialties, who do not participate in the work process proper, are involved in the study and analysis of the efficiency of the latter.

Finally, with the use of automated means of production, the functional direction of man's action is differentiated even more; there are greater requirements concerning time or speed of performance of actions, even more rigid organization thereof as a whole. The rigid, algorithmized organization of actions of, for example, an operator-observer or operator of tracking systems, does not always by far allow the operator to form the mode of action that is the most convenient for him and does not directly create a need to upgrade the quality of the end result. In fact, there is a change in the very content of the result. This no longer refers to the result of man's influence on some object by means of automated devices, but the result of changes that are caused by man's actions in the automated device itself. And the gages that determine the efficiency of the mode of system operation are transferred to man's actions. They include the gages of precision, speed and reliability.

Thus, the means of production itself becomes the immediate object of man's activity, while the requirements as to the result of interaction are limited by the operating mode or state. In practice, these requirements pertain only to the executory actions of man, and it is only when the device itself stops operating in the set mode that man is provided with the opportunity to perform certain cognitive actions to determine the causes of the dead halt. These actions are characterized more often by the measure of responsibility, rather than measure of need. As a result, one could have concluded that the meausres [gages] of executory actions that are established on the basis of efficient operation of the system should be the main criteria of work actions. However, under conditions of automated production, new types of occupations are appearing: operator investigator and administrator, which require a different approach.

In these types of activity, not only perfect proficiency in use of tools and means of labor, not only executory and cognitive processes, but processes of shaping or setting goals and choice of methods of reaching them play an ever increasing role. We refer to establishment of goals of quite concrete, inherent processes of labor and dynamic conditions under which they occur, rather than any external ones in relation to work activity. Ergonomic analysis of many modern types of work activity requires the mandatory consideration of human subjectivity, analysis of motivations and goal-setting processes, characteristics of subjective conception of the goals and change therein during the actual work process.

These requirements of ergonomic analysis are related to the fact that the goals are interspersed in the work process, than cannot be replaced with either labor sets or motives.

The subject of ergonomics is any activity insofar as it is included in the rather broad context of technological equipment [means]. This, of course, does not mean that ergonomics is identical to general theory of activity; its tasks are much narrower, and they are related primarily to analysis and purposeful planning of the existing types of work activity. For expressly this reason, as we have mentioned before, ergonomics makes a contribution to the development of general theory of human work activity in modern industry.

Serious difficulties are encountered in defining activity as the subject of ergonomic research. This is also attributable to the fact that there has been virtually no attempt made in our literature to differentiate between the concepts of "activity," "labor," "labor [work] activity," and the different usage thereof is intuitive rather that scientifically substantiated. In spite of the fact that there is much in common in the concepts of activity and labor, one cannot automatically make a distinction between their scope and content [10]. And such differentiation is far from a simple task. It is not even the problem that the concepts of labor and activity cross over one another. There is a complex system of correlations (development, function, etc.) between them. Labor is a condition of development of activity to the same extent as development of activity is a condition of development of labor. For expressly this reason, considerably more similarity than differences are found between them in general philosophical or sociological studies [10]. The situation is the same in ergonomics, which finds itself related to general theory of activity or general theoretical conceptions of man's activity. Methodologically, this appears to be quite logical: special scientific studies of activity should have as their theoretical and methodological grounds certain general conceptions about activity as a whole, about the laws of its organization and structure. In practice, however, as observed by E. G. Yudin, the matter is much more complex; modern scientific knowledge does not, in essence, have a theoretically complete phenomenology of activity as a whole; for this reason, there remains only one possibility for the investigator of activity if he tries to find and clearly lay the theoretical foundation to his work: to refer to conceptions of activity that were developed by psychology [62, p 338]. This is the route we followed in our analysis of the functional structure of executory and cognitive activity, which will be submitted in the next sections of this chapter.

2. Functional Structure of Executory (Perceptual and Motor) Action

In the Foreword to his "Essay on Working Movements of Man," published in 1901, I. M. Sechenov wrote that the subject of his essay "consists of questions of the complex muscular motions by means of which man performs so-called external work, i.e., he exerts the force of his muscles on objects in the outside world" [54]. Although the nature of "external work" has changed appreciably since then, and absolutely new types of work activity related to control of complex equipment have appeared, there is still validity to Sechenov's words, that work always was and always remains a vital function of the human muscular system, no matter how much modern technology eliminates from industrial life human muscular labor. It is imperative to analyze executory activity and demonstrate the general principles of development and inception of its functional structure in order to solve problems of control and optimization of such activity and to plan new forms and means thereof. This is needed to organize rational teaching and training, to develop perfect skills, to organize work and rest schedules that prevent fatigue.

In ergonomics, executory or controlling action refers to the ability (skill) acquired as a result of learning and repetition to solve a work problem using work tools (hand instrument, control elements, etc.) with specified accuracy and speed. As a rule, executory actions are included as a component in broader structures of work activity, and provide for efficient performance thereof, along with such components as cognitive, including decision making. Depending on the type of work activity, the share of executory actions varies quite significantly. These actions may be performed either sporadically, or throughout the entire work time. In other words, they may occupy the place of the main goal in the structure of activity as a whole, or else emerge as a means of reaching it, for example, transmitting a command, implementing a decision, etc. In the latter case, executory, motor acts are usually simple, and they do not require lengthy learning. In those cases where executory actions constitute the main content of activity (work with a hand instrument [tool], lathe operator work, driver occupations, telegraph operator, computer operator, work in the tracking mode), lengthy formation of the appropriate abilities and skills is required to assure prompt and precise performance of the work activity.

For a long time, for ergonomic implementation of these types of executory actions the traditional conceptions of motor and sensorimotor learning and conceptions of motor skills as automated and largely stereotype reactions arising with numerous repetitions of sensorimotor and kinesthetic acts were enough. The development of skills was usually described in terms of stimuli and reactions, reflexes, trial and error. When these elements were repeated, when this repetition succeeded or was reinforced, first separate reactions were replaced by complexes, isolated movements combined into integral kinetic structures, a sort of "motor form" or "kinetic melody."

For a long time, such an "nascent" or later on stimulus-reactive approach directed toward the result, the effect of a single, relatively simple action, constituted the scientific basis for the conception of "engineering design" of work methods that is linked with the names of F. Taylor and F. Gilbreth.

Time-related and motor analysis of elementary actions and operations served as the methodological basis of such planning. F. Gilbreth expounded the idea of universal micromovements (therbligs), of combinations of which, differing in composition and order of therbligs, any operation must consist. This idea was used at the plants of H. Ford, where the entire assembly work process was broken down, by means of thorough planning, into so many minute operations that a car was assembled while in continuous motion. Ford strived to have a worker perform a single job with a single motion. F. Gilbreth studied motion by means of time studies, photography, cinematography and cyclography. The principles of economy of motion that he formulated made it possible to eliminate superfluous ones, and to select out of all possible ones those that could be performed the fastest and required the least effort, as well as to achieve a reduction in intervals between successive movements. Practical tasks of work planning initiated studies of kinematic and dynamic characteristics of man's work movements. The results and methods of these studies, as well as the principle formulated by Gilbreth of economy of work motions, were used in solving problems of organization of work places, design of hand tools, arrangement of controls, etc.

Unquestionably, the systems of F. Taylor and F. Gilbreth made a substantial contribution to the study of elementary actions and operations. However, use of time and motor analysis of motion in the form that it was proposed could not demonstrate the structure and mechanisms of integral executory activity of man. In 1930, N. A. Bernshteyn wrote: "It must be stressed that not only the methods, but the very concept of rationalization of motion, are not as simple as was previously thought. The simple struggle of Taylor and later Gilbreth against superfluous movements and interpretation of a biomechanical operation as the simple sum of successive movements, which could be passed like grain through a screen, is beginning to yield its place to interpretation of the motor complex as an organically inseparable whole that always responds to changes in any part by readjusting all the others" [5, p 7].

Such an engineering approach to the planning of work (with all its initial usefulness) was submitted to valid criticism on several grounds. Monotony and little satisfaction with work are the obvious consequences of utmost simplification of work, of reducing it to single elementary motor acts. Both have an adverse effect on labor productivity.

As for the more complex types of work activity, this approach has already exhausted its "optimizing" capabilities. The complexity of executory action is growing to such an extent, that standard motor "forms" or even kinetic "melodies" cannot assure efficient performance thereof. We refer to the fact that in modern industry stereotypic work movements are gradually yielding to the performance of purposeful, wise, voluntary executory actions. In many types of work activity, protection against automatism, impulsive, reflex reactions is required more and more often. Erroneous actions, which occasionally lead to emergency situations, often occur because man was too hasty, and not because he did not have enough time.

This applies equally to a lathe operator and pilot. Modern mechanized and automated industry requires that man perform not only learned, assimilated actions, but actions that are, so to speak, unprecedented, which do not need to be recalled, but created in a new, unexpectedly occurring situation. There are increasingly frequent instances when it is impossible to reproduce all of the important conditions of a real labor process during occupational training, and final learning takes place when performing a work, executory action, rather than an exercise. Adjustment to real conditions is particularly difficult when performance of actions requires perfect sensorimotor coordination. The activity of cosmonauts, who must perform in weightlessness docking, separating maneuvers, move from one craft to another, engage in extravehicular activity in space, operate hand tools, make manual landings, i.e., handle controls under variable gravity conditions that transform customary sensorimotor coordination, the force pattern of previously well-learned motions, could be a vivid example of such situations. In particular, weightlessness affects more than the area of motor activity; it can elicit diverse unpleasant sensations, transient spatial delusions or even signs of depersonalization and derealization of the subject's perceptions.

The need to perform executory actions in the case of delayed feedback about the results of a performed action imposes a similar mental load. Among such actions are control of a LEM ["lunokhod"--lunar excursion module], where the delay does not exceed a few seconds, and control of a supertanker, where the lag in appropriate evolutions of the ship after performing a control action numbers a few minutes. The appearance of an entire series of relatively new types of activity, related to control of spacecraft and space stations, remote studies of planets, handling of radioactive elements, control of diverse moving objects, including robots, led to the distinction of operator-manipulator activity as a special object of ergonomic research. With this form of activity, perceptual-motor coordination and interaction play the chief role, although, of course, the system of graphic and conceptual thinking also plays a significant part. The executory actions of an operator-manipulator are performed by means of so-called "regulated motions," which require high precision, not only spatial but in time. This means that, from the standpoint of efficiency of their performance, the informative indicator is not only the end result of action (as in the case of depressing a button, key, tumbler), but the ongoing characteristics of motions that determine the dynamics of the object of control.

Perfect perceptual-motor coordination is also needed for the performance of many technological processes. A vivid example is the activity involved in manufacturing and operating microdevices. The dimensions of micro-objects and required density of their assembly also impose high requirements of the technology of producing them, so that instrument production on their basis has become a jeweler's job. The work of man engaged in the area of assembly, for example, of integrated circuits, is performed under conditions of constant visual monitoring, high tension due to the need to perform highly accurate and finely coordinated precision movements. The influence of these factors is complicated by the fact that the size of microdevices is on the boundary of visibility to the naked eye, and visual monitoring of technological operations is possible only with the use of optical magnifying instruments. It is a known fact that use thereof results in adopting a forced [contrived] position, hypokinesia, narrowed field of vision, etc.

Servicing of many lathes requires highly coordinated work with both hands under continuous visual monitoring. The time within which the coordinated movements have to be made should not exceed 60-80 ms in some cases. The need to optimize such forms of activity led to the distinction of activity of the operator-technologist as a special object of ergonomic research.

These examples indicate that a "nascent," stimulus-reactive approach to the study and optimization of activity of the operator-manipulator and operator-technologist cannot satisfy modern ergonomics. The motor acts, executory actions are interspersed in the fabric of broader structures of activity, and the success of executory actions should not be evaluated by itself, but within the context of these structures. It depends on how well man became oriented in a situation, i.e., on whether man formed the correct image of this situation and whether he found a way, sometimes the only possible way to act.

Formation of an image of a situation, creation of programs of rational action, precise and prompt performance thereof, monitoring its effectiveness--these are the problems that confronted modern ergonomics, as well as a set of allied disciplines, biomechanics, physiology and psychology, which have long since studied the organization, structure and control of human movements and actions.

Both the practical tasks that confronted these disciplines and the logic of their own development require formulation of new approaches to the study of executory actions. To counterbalance the nascent-reflex approaches directed toward an assignment, result, effect, etc., researchers are developing a structured, integral, activity-oriented approach directed not only toward learning, but constructing motions, actions, motor programs and schemes.

A thorough analysis of the pattern of motions, even when repeated many times in the same situation, is indicative of their uniqueness and distinction. A detaled analysis of the motor act shows that its biodynamic fabric is as unique as a fingerprint. This means that not only is the image of a situation and equivalent motor scheme is constructed, but on the basis of this scheme each living motor act is constructed (rather than simply repeated). The results and the progress of this work do not ensue unequivocally from the structure of exogenous stimulus reinforcement. In this sense, explanation of the motion that is performed with the "stimulus-reaction" scheme does not conform with the essence of the question. Researchers have still to develop concepts referable to this type of work, on construction of spatial motor action.

Motor action, viewed as a mandatory component of activity, must necessarily be correlated with its cognitive and personality components, such as, for example, image and goal. And, as we have indicated above, activity itself as a whole and all its components are of necessity characterized by objective-meaningful features and time and space certainty. The origin of this approach goes back to the names of I. M. Sechenov and C. Sherrington.

I. M. Sechenov repeatedly stressed that "feeling always has the significance of regulator of motion; in other words, the former causes the latter and alters its strength and direction" [55, pp 236-237]. It is also interesting that Sechenov did not limit the task for physiology and psychology to the study of separate movements, but spoke of the need to study the area of phenomena in which "feeling is transformed into motive and goal, while movement is transformed into action." At the present stage of studying work motions, work operations and actions, the most complex forms of man's executory activity, it is particularly important to mention the direction indicated by Sechenov in the search for a solution to the problem that is a cardinal one to this day for physiology and psychology: what is the mechanism of regulation of motion by feelings? The possibility of such regulation is already provided by the fact that a muscle, which is a "dual organ, our working organ and, at the same time, primordial, original sense organ, which educated as part of its properties all other sense organs, colors all our conceptions of the world around us in images of motion" [53, p 936]. Moreover, Sechenov wrote that the muscle gave us our conceptions of space, time, date, counting, etc. All this is possible only provided that motions and actions themselves are not merely elementary and utilitarian acts of execution, but that they also perform cognitive, learning and expressive functions. The latter is clearly implemented, not only through movements, but postural and tonic components of action, which carry its personality-meaningful content.

Many work motions and actions are so perfect, coordinated, expressive and beautiful that they are often included in dramatized performances. The idea of creating a special choreography of work processes, which has been voiced from time to time, is not without meaning.

The functional duality of a muscle, functional heterogeneity of motions and actions provide not only for potential, but actual integrity of activity, the possibility for it to develop and improve. In this sense, C. Sherrington made a remarkable assumption "... that the performance of actions directed toward a definitive, final act in the process of selection opens up the possibility for elements of memory (though rudimentary) and elements of forewarning (though insignificant) to develop into the mental capacity of 'running in reverse' from the present to the past, as well as ahead, into the future, which is a mandatory sign of higher mental development in higher animals" [60, p 314]. It is expressly this "mental capacity" that is the regulator of executory acts. I. M. Sechenov understood this very deeply, stating that feelings relayed to consciousness by sense organs do not serve directly as sources of motion, but via the psyche, since a certain meaning is related to a signal.

The difference between the nascent-reflex and integral approach is also fixed in the language used to describe motor behavior. For the former, mainly such terms as reactology, reflexology were used, and for the latter--psychomotor system, psychonervous activity, mental activity, etc. Of course, the use of the terms "reflex" or "reaction" per se does not yet signify that a given author is a proponent of the "nascent" approach. It is expressly in these terms that the original foundation was laid for the structured approach to the study of motion and action. Thus, C. Sherrington, in analyzing forewarning and concluding reactions, wrote: "It is not difficult to see what broad opportunities are provided for adaptive reactions by a device consisting of an entire chain of successive acts, each of which alters the influence of the preceding act" [60, p 312]. This quotation clearly discloses the idea of integrity [wholeness] of adaptive activity. Analogously, I. P. Pavlov, who analyzed chains of motor reflexes, arrived at the idea of dynamic stereotype as an integral element.

Since the times when I. M. Sechenov and C. Sherrington gave a psychological interpretation to motor behavior, numerous data have been accumulated on the decisive role of sensory processes in the control of human motion. A. A. Ukhtomskiy, who analyzed the structure of the anatomical system that implements the movements of higher animals and man, observed its originality, as compared to artificial mechanical devices characterized by a significantly larger number of degrees of freedom. Neither the bone and muscle system as a whole, nor any part of it forms a ready mechanism for the performance of any specific purposeful act, but represents only a set of certain anatomical components that are needed to form it. The structural distinctions of the skeletomuscular system impart flexibility to the behavior of higher animals and man, and at the same time render the task of controlling this behavior extremely complex and difficult. Since control implies a limitation of degrees of freedom, such restrictions are virtually lacking in the actual arrangement of performing mechanisms in living organisms, and the functions of regulation of performed actions have to be assumed by central mechanisms. Let us briefly examine the evolution of conceptions and current views of the mechanisms of control of movements.

Originally, it was believed that central mechanisms can perform this function using rigid standards that predetermine the nature and sequence of required movements. R. Woodworth [80] introduced the term "central" or "motor" programming for this means of construction of motion. He proved the existence of motor programs in studies of rapid voluntary movements of man.

Analysis of the kinematic characteristics of precise hand movements led him to the conclusion that there is a phase of motion that is independent of visual feedback, a phase that is determined by the original program. In addition to this phase, there is a second one that is performed with consideration of visual feedback and which implements that precision features of motion. Thus, Woodworth described the means of controlling motion that were later named control through open and closed loops of regulation. At the present time, each of these means has been largely absolutized and has its proponents. A considerable amount of experimental data has been accumulated in favor of each of them; debates are taking place between representatives of theory of open and closed loops.

K. Leshly was apparently one of the first to distinctly formulate the conception of central motor programs and experimentally prove that development of a skill is a centrally organized process, in the implementation of which proprioceptive mechanisms may not necessary play a significant role. The conclusions of Leshly, referable to the fact that a learned skill could be implemented by various motor structures do indeed confirm the idea of motor programming, but at the present time they are virtually not used as evidence of the minor role of kinesthetic control. The search for proof of an open loop proceeded along the road of studying rapid ballistic movements and blocking feedback channels that function in performing motor acts. The proponents of the conception of motor programming and open loops relegate to afferentation only triggering functions and modulating influences. However, no conclusive evidence has yet been obtained to the effect that man's voluntary movement can take place only as the result of centrally organized nervous commands, that are structured before the start of a movement and permit performance thereof in the absence of peripheral feedback.

The main flaw of open loop systems is that they do not have feedback mechanisms to correct mistakes that occur as a result of both the properties of their inputs and transformation of signals within the system. This type of system has poor compensatory capabilities.

Conceptions of motor programs were developed comprehensively within the framework of the open loop concept. Motor programming means that the sets of motor commands, both inborn and learned, are stored in the central nervous system, and can be evoked and synthesized into the desired motion. A motor program is a meticulously coordinated order of synergies (they are sometimes called subroutines, or submodes) that together involve the required motion and are independent of feedback.

Regardless of the attitude of proponents of the open loop concept toward involvement of feedback in regulation of motion, they have developed some interesting ideas about the hierarchy of motor programs, existence of generalized programs, program-schemes, the lower elements of which relieve the main program from laborious calculations. Of importance also are the hypotheses of a link between programs, motives and goals, which are transformed into a certain internal conception of the subject about the desired, required motion or action. In other words, motor programs are more closely related to the image of a situation, image of action, rather than only to a set of commands stored in the nervous system. The open loop conception of regulation has been used, with minimal stipulations and limitations, to interpret the mechanisms of human eye movements. Numerous studies established virtually the same correlation between speed of the jerk at the initial start of movement and ultimate amplitude of the jerk. This means that the velocity of the saccade was programmed even before the start of movement. On the basis of electrophysiological studies, it was concluded that control of saccadic movements in one fixed direction amounts to determination of the time segment within which a constant force is applied that contracts the rectus muscles of the eye.

We find the seed of the opposite ideas of a circular or closed loop of motion regulation in the works of W. James [70], C. Sherrington [60] and others.

James assumed that peripheral feedback from one part of a movement brings the next one into action, and he expounded the hypothesis of "chain reflexes," against which Leshly spoke later on. According to closed loop theory, it is assumed that a response is not merely triggered by the receptor system, but controlled by it.

Control of movement via a "closed" loop implies transmission through feedback of information about conformity of the movement with the required goal and elaboration on this basis of new control commands. Feedback serves two functions: with it determination is made of the spatial characteristics of the goal that are required to form the program of ballistic movement, as well as correlation of the results of implementing such programs with the actual position of the goal, which serves to adjust the programs for subsequent movements. N. A. Bernshteyn provided the most complete argumentation for the fact that rigid programming cannot assure the purposeful effect of movement.

The theory of N. A. Bernshteyn deals with a wide class of functionally different movements and is a general theory of level-by-level control and formation of human movements. This theory is comprised of three basic principles: central programming, sensory corrections and level-related organization of movements. It describes the principle of coordination of movements in a faultless form from the standpoint of modern theory of automatic regulation: "... as soon as an organ that is under the influence of exogenous and reactive forces plus some added endogenous, muscular force deviate in their resultant motion from what is intended by the central nervous system, the latter receives an exhaustive signal about this deviation, which is sufficient to make adequate adjustments in the effector process. For this reason, this entire principle of coordination deserves to be called the principle of sensory corrections" [6, p 28].

For a long time, N. A. Bernshteyn emphatically rejected any possibility of control of movement via an open loop. However, later on, he retreated from such an extreme point of view and conceded that there was a possibility that, in some elementary processes, the arc is not closed into a reflex ring, either because of the brevity of the act or its extreme simplicity.

Sensory corrections are made, in the general case, by all of the receptor systems available to the body. In special cases, some of the feedbacks do not necessarily participate in the control of movement. The primary receptor signals are first submitted to complex processing and "recoding," which is needed for example, so that they can be compared to the plan of movement made in the language of spatial and kinematic conceptions. The "syntheses" obtained as a result of processing, which consists of signals of all types of feedback involved in controlling a given movement, serve for sensory corrections.

In the model of Bernshteyn, the concept of sensory synthesis plays a basic role. The composition of afferentations that form it, i.e., feedback, and the principle of their combination serve as the main criterion that distinguishes one level of forming movement from another.

Each motor tasks finds its own main level, depending on its content and meaning-related structure. Levels differ from one another, not only in type of sensory synthesis, but anatomical substrate, i.e., the aggregate of nervous system organs without which implemention of function of this level is impossible.

One of the levels takes the lead, coordinating the action of underlying background levels, depending on the purpose and meaning of the motor act.

Only the leading level is perceived in any movement. Development of a motor skill is a process of formation of the level composition of movement in the course of learning and conditioning, singling out the leading level and coordination of all levels involved in control.

Development of an adequate method is a mandatory prerequisite for successful studies of motor acts; it would permit recording and analyzing the time and space evolution of movement, the entire course of the motor act "over the entire motor system of the body." In studies of executory activity directed toward demonstration of objective indicators of the process of formation of a sensorimotor image of space and structure of action, the microstructural analytical method was used, which consists of isolating rapid components of integral mental acts and analyzing their correlations. Use of this method in studies of voluntary spatial actions permitted disclosure of the structure of spatial action, tracking the dynamics of its inception and development under different conditions of action, isolating several component stages: formation of the program, execution, control and correction, component structures of action, dynamics of their development, correlation between them at different stages of learning the action, as well as changes occurring within the isolated components of an integral action (see Chapter III for a description of the method).

The experimental situation involved the study of formation of instrumental spatial action under different conditions. Under stable conditions, the trajectories of the required movement were of the same size and complexity. Under dynamic conditions, the trajectories differed in number of support [reference] elements and number of spatial components of movement. In the case of inversion, there was a mismatch (complete or partial) between the perceptive and motor fields. Inversion was introduced after development of the skill under normal conditions.

As a result of this study, it was found that there are complex dynamics of correlations between different stages of an integral action in the course of development of a skill (stable conditions, norm). In the first place, in the course of learning [mastering] a spatial action there is a reduction in time of each isolated stage; in the second place, the time reduction in each stage occurs unevenly; in the third place, as conditioning progresses there is redistribution of time among the isolated stages. The nonuniformity of rate of reduction of time in the isolated stages indicates that all components of integral action are disssimilarly refined. The studies demonstrated the sequence of formation of components of a spatial action. The stage of formation of motor programs is the fastest, followed by the stage of control [checking] and correction; both are formed against the background of gradual decrease in time taken up by the stage of implementation of motor programs. Only after both cognitive components are formed is it possible, apparently, for the last reduction in time of performance of the action as a whole. This reduction is referable to the executory part thereof. The redistribution of time among the stages within an integral action at different stages of formation indicates that each new exercise is a new problem solving process, a process of change and refinement of the ways and means of solving it.

When using inversion as a means of disrupting a formed spatial action, it was demonstrated that subjectively the process of formation of a skill in the presence of inversion is experienced as considerably more difficult than the norm. Formation of a skill with any form of inversion (total or partial) alleviates adoption of any other type of inversion. The change from the norm to any type of inversion occurs with great difficulty and requires more time than the change back. A comparison of the course of formation of compatible and inverted instrumental spatial action shows that when changing to work with inversion there are effects of transfer and interference (Figure 10).

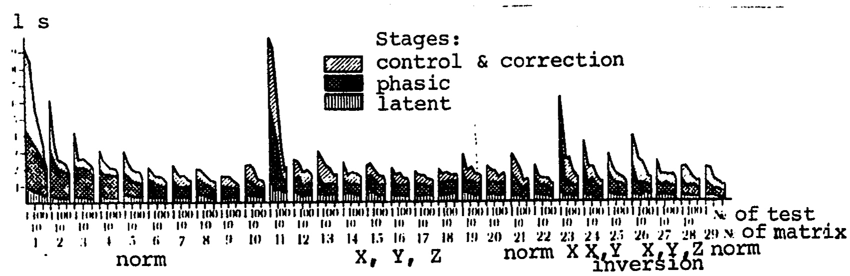

Figure 10. Dynamics of process of formation of instrumental spatial movement (3-month interval between 6th and 7th, 9th and 10th, 25th and 26th matrices)

One observes different dynamics of behavior of functional components in the course of change in a skill, analysis of which leads to the conclusion that faster than normal formation of an inverted skill is possible by means of transfer of phasic, speed-related features of spatial action.

The implementation stage retained virtually all of its characteristics. Inversion of perceptive and motor fields had a negligible effect on speed characteristics of the phasic elements of action. In the case of cognitive components, we are not dealing with transfer, but interference of the spatial image formed under normal conditions and the image that is just being formed under inverted conditions. This affected the nature of the cognitive elements. Moreover, expressly this affected the characteristics of the implementation stages at the early phases of formation of a new action under new conditions. The phasic part of the action again assumed cognitive functions. By means of hand movements, the subjects palpate new space and find the features of this space. When a new sensorimotor image of space is formed, the stage of implemention is relieved of cognitive functions and begins to operate as in a compatible spatial action, but now it implements other programs. The cognitive components continue to be refined but no longer with visible participation of the implementation stage. Thus, the phenomena of transfer and interference are different in nature. Transfer occurs at the expense of the performing [executory] part of action and interference, of the cognitive components; however, these phenomena are not mutually exclusive, they interact in each spatial action.

The dynamic conditions of presenting information affected chiefly the characteristics of cognitive components of the process under study, analogously to the changes recorded with introduction of inversion. The particularly drastically changing conditions of presentation of information affected the characteristics of the control and correction stage, the time of function of which is 2-3 times longer than the time required for control under stable conditions. This is related to the fact that in the presence of uncertainty a dual load is imposed on the control and correction stage: not only to check each discrete action, but also, what is particularly important, relate the conditions of presentation of information to the action performed. In other words, the control function includes not only checking the result of action, but control of consistency of the chosen program with the action to be performed. The results of this study provided new material for investigating the process of formation of a sensorimotor image of a work space, based on active actions, the cognitive component of which is the most important at the first stage of formation of the new action. It is obvious, from the data on the indicator of cognitivity, which characterizes the dynamics of time relations between cognitive and executory components and is manifested by the ratio of sum of time of cognitive components to the executory one, that as a skill is acquired the share of cognitive components in the integral action diminishes. When an image of sensorimotor space is formed, the function of cognitive components is reduced to programming the performed action which, of course, affects the reduction in the indicator of cognitivity. As compared to dynamic conditions of presentation of information, under stable ones the reduction in value of the cognitition indicator is expressed because the control function is more reduced under static conditions.

At the first stages of formation of a new action, whatever the conditions, there are vague boundaries between stages. The scatter between elements X, Y and Z within each stage is so wide (in some cases up to 1 s) that the impression is created of one stage entering into another. This is quite consistent with the thesis formulated within the context of the structural systems research, according to which a less developed structure is characterized by less differentiation of its components. This leads us to two hypotheses: first, at the early stages of learning there may be parallel execution and implementation of the program, as well as implementation and control; the second, which ensues from the first, is that, at the early stages of formation of a skill, execution of the program, its implementation and control proceed separately in movement components. In other words, there is successive planning of movement in each coordinate. Analogously, there is successive implementation and control. The learned action is characterized by a significant decrease in scatter, and since it is scatter that characterizes the quality of action (its spatiality), at the final stages of learning the formed action acquires features of a more distinct functional structure. And while the functional structure of action is comparable, according to the index of spatiality, for different conditions of action at the early stages of learning, at the end of learning the actions formed under dynamic and inversion conditions are comparable, being 2-3 times greater in scatter than this parameter under normal conditions. Consequently, introduction of inversion or uncertainty consistently worsens the quality of action, as manifested by an increase in values of the scatter index. In other words, the quality of action is extremely sensitive to various changes made in the conditions under which it is performed.

Knowledge of the functional structure of action, studies of the dynamics of its formation and inception, demonstration of interrelations and correlations between components of the object studied offer the possibility of controlling the process of formation and optimization of movements and actions.

The change in share of components in the structure of action, both during its formation and under the influence of some changes or other made in the conditions under which it occurs, indicates that prevalence of some type of regulation of motor acts is related essentially to the conditions under which the action takes place and the degree of assimilation, learning. Figure 11 illustrates the shares of components of an integral action taking place under different conditions and at different stages of its formation.

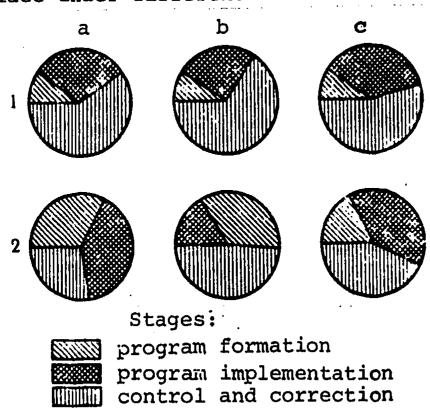

Figure 11.
Share of components of formed spatial action under stable (a), dynamic (b) and inversion (c) conditions:
1) start of learning
2) end of learning

The correlation between components of the functional structure of an integral action is similar at the start of its formation, regardless of the conditions under which the action occurs. At the end of such formation, a similar correlation between components of action structure is observed in actions formed under dynamic and inverted conditions; an action formed under normal conditions has a very different structure. The situation of inversion and dynamics and the normal situation can be compared in terms of open and closed control loops. Under normal conditions, the subjects formed a simultaneous image of the situation after lengthy conditioning, and the program that organizes the motor response, i.e., a significant part of the action, appeared to be implemented over an open loop, as confirmed by the significant share occupied by the stage of formation of programs and relatively small share of the control and correction stage. In the inversion situation and under dynamic conditions of presentation of information, during the experimental series there was retention of regulation by the closed loop principle, as indicated by the share of the control and correction stage, which constituted about 50% of the integral action.

Many diverse variants of closed loop of regulation have been proposed to date, and they describe more or less complex acts of human behavior and activity. These theories refer to such processes as discrete and continuous motor processes, perceptual-motor skills, verbal behavior, etc. The general features of these theories are that the closed loop implies that the subject is aware of the course of performance of movement. Such knowledge is gained by means of feedback from movement and is directed toward control of this movement. The closed loop is based on checking information from elements of the system, "calculation" and consideration of errors indicating the direction or degree of deviation of the system beyond the set range, and correction of such errors. The main function of closed loop systems is to minimize these errors.

J. Adams [63] proposed an interesting variant of closed loop control of movement in development of motor skills. In developing his theory, Adams made wide use of the conceptions of P. K. Anokhin pertaining to action acceptor, N. A. Bernshteyn concerning the setting element and comparison system and Ye. N. Sokolov concerning the nerve model of a stimulus.

The theory was expounded to interpret the process of learning simple, discrete movements performed in a moderate, unimposed pace, i.e., it is the theory of formation of a motor skill. It applies, first of all, to linear movements of the hand over a specified distance without the subject seeing the mark showing the required end position of the hand, while the distance is given to him in either verbal form, or else he learns it in the course of training by shifting his hand up to the stop in a limiting device.

According to Adams, in a closed loop mechanisms by means of which information received over feedback channels is compared to the standard for detection of errors occupy the central place, i.e., it is assumed that a standard mechanism exists in the system, in which the specified action is fixed, as well as feedback channels,system for making comparisons, isolating and correcting errors. Knowledge about the results of each performed movement is of first and foremost significance to formation of skills. Man uses this knowledge to alter movement and eliminate or attenuate errors in each successive trial. Such successive corrections ultimately lead to development of the correct movement. The standard mechanism is called the perceptual trace, which consists of information of previously performed movements stored in memory.

The concept of a perceptual trace is the equivalent of the concept of nervous model of a stimulus [56]. The perceptual trace is a mechanism that determines the amplitude of movement and, perhaps, time organization of movement. In the general case, all forms of feedback are sources of formation of a perceptual trace: visual, auditory, proprioceptive, as well as tactile and pressure receptors. The stability of a perceptual trace increases with increase in number of trials. Information about early, inaccurate trials is forgotten, and there is an increase in "weight" of the most recent tests performed with great precision.

However, learning a movement is not reduced to such a simple scheme, according to which it would be sufficient for a perceptual trace to be formed and for the stimuli of current feedback to conform with it. At the early stage of learning, conscious and verbalized knowledge of the results is of decisive significance. This stage is called verbal-motor. It ends when a satisfactory result has been obtained in a series of performances, and there are few errors. After reaching a certain level of perfection, the perceptual trace is fixed. Further learning can then proceed without knowing the results. Instead, there is comparison of feedback information to a highly accurate and stable perceptual trace. This final stage is called the motor stage.

Adams offers logical evidence of the existence of a special mechanism, the function of which consists of initiation and choice of movement, which is called a trace in memory. A memory trace functions in an open system, controlling by program, without correction, the feedback of movement at the initial stage. The action of memory trace and perceptual trace does not coincide in time. At first, the memory trace is involved in control and somewhat later, when feedback signals begin to be received, control is transmitted to the perceptual trace. In other words, a memory trace is a motor program which merely actualizes the mechanisms needed to implement the reaction and triggers them, but does not control the execution of a longer sequence, as is generally implied in the open loop conception. Some movements are executed only on the basis of the memory trace, if the motor reaction can be classified as being ballistic. Such a reaction is initiated by the memory trace and ends before the subject is able to adjust it in the performance process, comparing the received feedback to the perceptual trace.

It must be stated that the explanation of ballistic movements performed within 100-200 ms presents the greatest difficulties for the closed loop conception, since correction in such cases must be made before the movement is completed. The hypothesis that motor control is planned prior to the start of movement is expounded to explain such cases. The fact that man can perform a movement lasting no more than 100 ms was used as the strongest (true, still indirect) argument in favor of the open loop conception. However, current studies in the field of physiology of proprioception yielded numerous facts indicating that proprioceptive feedback can occur within substantially less than 100 ms. Cortical potentials from nerves located in the tongue and extremities are recorded within 3-5 ms. The full cycle from the muscle receptors of the eyes through the brain and back again occurs in 10 ms. A cortical response to a hand movement is recorded after 10 ms, while the total interval between delivery of motor stimulus (through the cortex) and EMG response constitutes only 30-40 ms. Thus, the motor system has the required "neuronal speed" to regulate movements in a closed loop, and feedback was used not only at all learning stages, but in the performance of each individual motor act [75].

Bearing these facts in mind, we cannot fail to give attention to the rather important circumstance that the "neuronal speed" and speed of human actions do not coincide. For this reason, the speed of conduction of neural impulses cannot be interpreted as indirect proof of the potential possibility of passage of information through the feedback channels. Direct proof of this must be obtained in a psychological, behavioral experiment.

The conception of J. Adams is an appreciable contribution to the solution of the problem of constructing and controlling movements. At the same time, we cannot fail to note that Adams' persistent rejection of the possibility of constructing programs and their involvement in regulation of movement, even in the variant of generalized schemes, is a step back from the theory of construction of movements proposed by N. A. Bernshteyn.

In recent years, an increasing number of works has been published, in which the alternative between conceptions of open and closed loops is overcome, and an effort is made to combine the strong points of both conceptions: construction of the program and correction of movements as they are performed by means of feedback channels.

We mentioned above that there is a fortunate combination of open and closed loop conceptions in the theory of N. A. Bernshteyn, i.e., he introduced both a program and feedback in his model of construction of movements. R. Smidt made an analogous attempt at combining the two conceptions, but with consideration of the latest advances in theory and practice of studies of movement; he analyzed both theories and arrived at the conclusion that he was faced with several difficult problems [75]. The first problem is related to storage and call for motor programs, the number of which is inconceivable, if we accept the thesis of "one motor program--one movement." Closed loop theory also does not eliminate the storage problem; moreover, in this case, not only programs, but standards of accuracy to which each movement must be compared have to be stored. The second problem is related to the appearance or formation of new movements. Theoretically, the problem is formulated as follows: where are the programs or accuracy standards taken from if the performer can produce movements that had never been performed before in the very same way? Finally, the third problem is the question of how the individual arrives at detecting his own motor errors and increasing accuracy of subsequent actions. Also unclear are the mechanisms of detection of two types of errors, which have different sources: "noise" in the sensory or motor systems, or the environment. These difficulties prompted R. Smidt to propose a compromise variant, schema theory which, as he conceived it, eliminates them to a significant extent. He proceeds from the fact that both mechanisms of regulation are used widely in the system of movement control, and for this reason there is no sense to classifying systems as only open or closed. However, the relative role of each of them differs substantially, depending on the type and complexity of movements, time of performance thereof and system level studied. For example, a computer can, on the one hand, be viewed as an open loop system, since it can operate without taking into consideration any mistakes that may be present in the program; but, on the other hand, it would be a closed loop system, since the programmer can detect the error after running the program and make changes in the next series. Similarly, an open loop system could have a feedback loop that prevents the program from, for example, dividing by zero, and if such an attempt is made the internal feedback loop can detect this and make changes in running the open loop program.

Analysis of numerous data leads to the conclusion that there are no motor programs of human behavior that produce movement without feedback. The motor program gives motor systems all details of the work required for the limb to travel the distance to a certain target, and feedback is needed to reach this target. But if it becomes necessary to alter the target [goal] of movement because of a change in the environment, the program must be run as before for a certain time (about 150 ms), until the movement readjusts to reaching the new one. In this case, feedback mechanisms are actively involved in reaching the "wrong" target under different conditions. Smidt defines the motor program as a set of preconstructed motor commands, which are expressed, after activation, in movement directed toward reaching the set goal, and these movements are not affected by peripheral feedback that reports about the need to change the goal.

As he develops schema theory, which is called upon to combined the open and close loop conceptions, Smidt postulates that there are two states of motor memory: one for calling and the other for recognition. Recall is the structure that is responsible for generation of impulses to muscles that perform the movement (or make a correction), whereas recognizing [or identifying] memory is a structure responsible for evaluating the feedback produced by movement, which permits production of information about an error in movement.

In schema theory it is also assumed that there are "generalized" motor programs created within the central nervous system and containing muscle commands with all the necessary details to perform the movement. The role of the program varies, depending on the duration of movement.

In the case of rapid movement (i.e., one lasting less than 200 ms), the motor act is under the complete control of recall [memory], in which the program determines all details of movement in advance.

In the case of slower movements, a motion is made with the use of both recall and recognition together. The role of recall in this case consists of production of small corrective motions, while the main factor that determines the accuracy of performing the assignment is a comparison of expected and actual feedback. Consequently, slow movements depend on recognizing memory, although the subject could make corrective movements with the use of recall.

Open and closed loop theories, as well as different variants of combinations thereof, constitute a substantial contribution to understanding of the mechanisms of formation and control of human movements and actions. An arsenal of functional elements that are important to comprehension of regulation of movement has been accumulated in studies, upon which these theories are based. A more complex research problem must be solved next: determination of different types of relations between these elements. Without solving this problem open and closed loop theories cannot presume to be the needed scientific basis for practical rationalization, organization and planning of new types of work activity. However, with all the originality and substantiation of several important theses, the are still general, competing theories of construction of movements, and they require not only coordination, but development, more details and experimental verification, as well as, perhaps, correction of some theses. Practical experience in ergonomic work indicates that it is far from a simple matter to turn from general theory developed in physiology, biomechanics or psychology to the solution of practical problems of optimization or planning of activity and its means.

To ergonomics, it is not enough to maintain that the theoretical extremes converge, and that in real activity there is close interaction between programmed and circular [ring] control of man's movements and actions.

Ergonomics is concerned with the specific range of independence or convergence, interaction between the programmed and circular means of control as applied to various types of movement and specific conditions, including timing.

The tenacity of opposition between open and closed loop theories is attributable to the following circumsntances. Movements that were too different in their biomechanical pattern and objectives were taken as objects of research. Natural and instrumental, isolated and chain (series), fast and slow, inborn and learned, and evoked (reactive) movements were studied. Methods were used to study them that had different resolution capacities, ranging from simple observation to rather sophisticated methods of recording the timing and spatial pattern of movements. Organization of movements was studied on different levels, and there were not uncommon cases of generalizing results obtained on the psychophysiological, neuropsychological, biomechanical and psychological levels. Finally, in many studies, motion was either considered as a whole without sufficient separation into its structural component, or else individual elements, isolated from the structure of movement as a whole, were the subject of investigation. All this caused and now causes great difficulties with regard to comparing results of different studies. For this reason, as before, it is still a pressing scientific and practical task to overcome the opposition between open and closed loop theories of regulation.

In these theories, as well as in the experimental studies on which they were based, not enough attention was devoted to analysis of the object-oriented content of activity. And even the motor acts studied were usually extremely elementary and seldom exceeded in their complexity the standard variants of stimulus-reactive schemes for studying motion. The means of recording motor acts were intended primarily for physiological processes occurring during performance of movements.

We were also impressed by the interpretation of the obtained data, which is made primarily in terms of automatic regulation theory, or cybernetics. The very names, open loop theory, closed loop theory, are indicative of the influence of the ideas and methods of cybernetics. Of course, there is nothing prejudicial in this influence, and some useful analogies to technological systems and control of man's executory actions did indeed help clarify many questions and led to formulation of new problems. N. Ye. Vvedenskiy once wrote: "Unfortunately, the constructions in the living world are so complex and original that their meaning is usually learned only after physicists and engineers arrive at the same results by other means" [15, p 574]. But he also warned that, when observing the activity of some tissue or organ "one should not overlook the fact that one is always dealing with living entities whose activity is put under the same conditions as all living organisms" [Ibid, p 566]. There is a great temptation to consider, by analogy to technological devices, an organ or function as a mechanism intended only for a certain job, i.e., out of context with the conditions under which its vital functions take place. However, any analogy has its limits and boundaries. Analogies between the eye and camera obscura or photographic camera became outdated long ago. We are not dealing with the fact that open or clos-' loop theories have already experienced the same fate, but that an even broader view must be developed about human motion and action, including them in the context of vital functions. At the present time, both theoretical and methodological conditions have emerged to overcome the opposition between open and closed loop theories. The theoretical prerequisites consist of the fact that, in many areas of research on mental activity, the technological, engineering approach, including its current information-cybernetic variant, is being successfully surmounted. The methodological conditions refer to the fact that, thanks to the use of computers on the experiment line, basically new opportunities have appeared for recording and analyzing movements.

As an example, let us mention a study [52], the subject of which was to analyze the correlations between cognitive and executory components of an instrumental action. The experimental situation provided for rapid and accurate horizontal movement toward a target, which was a light square equal in size to the controlled [guided] square and appearing from right and left of the starting position on the horizontal axis of a television screen following a computer program. Time and velocity characteristics of movement were recorded.

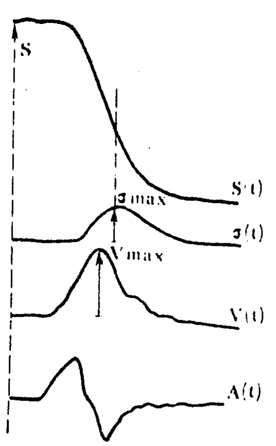

Figure 12.
Sample of tracing of movement toward target with characteristics of movement time S(t), scatter σ(t), velocity V(t) and acceleration A(t)

Figure 12 illustrates a sample of tracing of the movement toward a target, including the tracing of the parametric curve of trajectory as a function of time, data pertaining to velocity and acceleration of movement. The appearance of curves S(t), V(t) and A(t) describes movements directed toward rapid and accurate superposition of the controlled spot and target. The rate of movement increases up to the middle of the trajectory, then begins to drop monotonously until corrective movements begin which lead the controlled spot to the target. In turn, the change in velocity is due to the fact that the force applied to move the hand in space and, accordingly, the tool that it controls change in time. The nature of change in this force is described by a change in acceleration of movement in time

A(t) where we can distinguish a faster segment corresponding to the start of movement when velocity grows from 0 to a maximum, and the part of movement when acceleration is negative. At the same time, for each group of performances (depending on amplitude of displacement), calculation was made of the standard [mean square] scatter (σ), i.e., determination was made of the segments of maximum and minimum deviation from the ideal curve. As shown by analysis, maximum deviation of curve (σ) is observed half way to the target, where the velocity curve shows that it has reached its maximum. In other words, the scatter is at a minimum at the start and end of the trajectory. Hence, it may be assumed that the movements at the very start of the trajectory, which correspond in time to the phase of progressive acceleration and are characterized by minimum scatter (σ), are performed in accordance with a well-prepared program for this group of movements.

These data are consistent with the data of proponents of programmed or open type of control of movements, who postulated that there is a set of motor programs, which can be synthesized into the desired movement, cover it entirely and which are independent of feedback. The results of this study indicate that a programmed type of control is present only for the first part of a movement, lasting 125-150 ms for the above experimental situation and gorup of movements. As was demonstrated, the standard scatter increased, reaching a maximum on the section of the trajectory corresponding to maximum velocity covering an interval of 225-275 ms on curve S(t). Because of the many degrees of freedom of kinematic chains of the human body, effect of reactive and exogenous forces and other causes, no system of triggering afferent impulses, even the most accurately measured, can unequivocally determine the required movement. But the movement is made anyway, and rather accurately at that; and it is made by means of corrections in the course of performing it, on the basis of efferent signals received during the motor act, by means of "sensory correction." However, the impulses delivered to the nervous system during performance of the movement are not enough to control the action, they must be compared to their set, programmed values, which makes it possible to make corrections during performance of the action; correction of the motor act is made on the basis of such comparison. In other words, there are grounds to combine two types of control in one motor act, programmed and the one based on feedback, i.e., closed type of control.

The very conceptions of motor program and feedback, which are central to these theories, also require explanation, particularly since they are considered in these theories primarily from the standpoint of their physiological mechanisms. Yet, contemporary research is disclosing such complications, variations and directions in human action as are unknown to biomechanics and physiology, at least not in their present state. The main difficult is, apparently, that both the program and control are derived from the image, just like the image is derived from action with an object. This is not a logical circle, and for this reason it does not have to be broken; but it is necessary to understand the correlations between action and image, otherwise it is impossible to solve the problem of construction of movements. It is not by chance that we have quoted above the statement of I. M. Sechenov to the effect that feelings serve as sources of movements through the psyche, rather than directly, i.e., through the image that itself is just as dynamic as the movement it regulates.

Comprehension of this circumstances distinguishes radically the theory of N. A. Bernshteyn from open and closed loop theories. With reference to the function of the "setting" element, he very validly raises the question of the origin of macroprograms of goal-oriented action and its relation to a motor problem. The latter is directly or indirectly determined by the situation that has developed at a given time. In Bernshteyn's theory, the image or representation of the result (final or stage-by-stage) of action is the decisive factor in the appearance and formation of macroprograms of a motor act. "The fact that I refer to the concept of image or representation of result of action, which belongs to the realm of psychology, to characterize the main element of the motor act, with emphasis on the fact that we are still unable to name the physiological mechanism upon which it is based, by no means signifies that I do not recognize the existence of the latter or that it is outside the field of our attention. At the present time, we are able to find and name with a specific term the psychological aspect of the prime factor being sought in the inseparable psychophysiological unity of planning and coordination processes, whereas physiology, perhaps by virtue of the fact that it is behind in the research of movements, ... has still not been able to disclose its physiological aspect. However, 'ignoramus' does not mean 'ignorabimus'" [7, p 241]. In spite of this distinct formulation of the problem of regulatory functions of an image, we cannot fail to note that N. A. Bernshteyn discusses these functions in their most general form. Obviously, it is expressly in this point that he refers to psychological research, which cannot bypass the problem of formation of an image that emerges as a regulator of a voluntary motor act.

Consideration of orienting-exploring, cognitive components was an important stage in the study of voluntary movements and skills. A. V. Zaporozhets demonstrated that an image of the situation and actions that must be performed is formed in the course of orienting-exploratory activity. The contribution of orientation is particularly significant at the first stages of formation of voluntary movements [28]. Logic led A. V. Zaporozhets and his colleagues to differentiation between orienting-exploratory, testing and actually executory actions. New arguments appeared in favor of the multifunctionality of movements that can perform both executory and cognitive functions, which led to creation of theory of perceptual actions [29-32], development of methods of microanalysis of cognitive processes, including perceptual ones. And executory actions proper were analyzed only in the most general form: only the time of their performance and accuracy in reaching the goal were assessed.

Development of theory and methodological armamentarium for the study of perceptual actions enables us to formulate the task of combining a number of approaches for the study of voluntary movements and skills: theory of construction and development of movements of N. A. Bernshteyn and A. V. Zaporozhets, open and closed loop theories (along with the different variants of combination thereof), and theory of perceptual actions.

The first attempt at such a combination was made on the basis of microstructural analysis of executory and cognitive activity.

The following was advanced as the essential theoretical basis of necessity and usefulness of combining these conceptions. In the construction of movements the superfluous degrees of freedom of kinematic chains of the human body are overcome. The hypothesis that there is something in common between the task of constructing movements and the task of constructing a visual image is not without grounds. In image construction, superfluous and inadequate variants of reflection of the same object are also overcome. From the standpoint of regulation and control of voluntary movements, apparently it could not be otherwise, since the visual system represents a substantial part of the regulatory element of a motor act. For this reason, there must be as many degrees of freedom in the regulatory element (which, incidentally, is not necessarily related only to the visual system) as in the executory one. Otherwise, several of the degrees of freedom of the performing [executory] element would inevitably slip away from the regulatory one [36].

For expressly this reason, proceeding from the principle of innervation of separate muscles, one cannot explain the integral act of movement, one cannot discuss similar relations between innervation impulses and the movements they evoke. Ideas that are similar in meaning have been voiced by M. Turvey [78], who believes that pruposeful movements are not regulated by a rigid (prepared in advance) pattern, but by an image of action that is itself a constantly forming structure. It is unlikely that there is a ready regulatory pattern (standard) for each mode of performing a movement, particularly since the use of many modes of movement and action is possible without prior learning. Movement is performed by means of matching with one another the structures to be coordinated, which are relatively independent from the standpoint of organization of movement. Formation of movement proper could be viewed as a heterarchy, in the higher regions of which there is a small number of large and complex coordinated structures, and in the lower regions a large amount of small and simple structures. Turvey also believes that the image of future action or conception of it occupies the central place in organization of movement. According to this interpretation of the process of control of movement, the initial conception of action must be uncertain, as compared to the final conception in the executory commands for muscles. To put it in a simpler form, the "image of an action" cannot and should not be constructive in relation to the concrete details of the motor act. The action image includes a general evaluation of pose or body schema and isolated perceptive properties that may be needed to control the movement, which are also represented in a general form. In a developing movement, the "action image" is gradually defined at the subsequent levels of movement control by means of addition of detailed object-related content. The combination of coordinated motor structures occurs on each level by means of the corresponding, visually isolated properties of the environment. It is imperative to determine how and on what basis an activity is formed that is new to the individual, what its functional structure is and what are its components.

To answer these questions, inversion was used in an experimental situation as a means of disrupting a formed skill, with which the perceptual and motor fields, each individually, did not actually undergo any changes. There was merely impairment of consistency between movement of the key [manipulator] and displacement of the spot on the screen; in other words, inversion impaired the customary correlation between the perceptual and motor fields which, of course, disrupted the sensorimotor image of space that was formed under compatible conditions, i.e., the means became inconsistent with the goal. Use of inversion made it possible to track more thoroughly the stages of development of a new sensorimotor image of a work space [18, 19].

Let us discuss in more detail the structure of the phasic stage of spatial action, which changed with inversion from spatial, unique and purposeful into a set of many movements in different directions, either alternating with full stops or significant delays. Each such stop indicates that, having made a small movement, the subject checks himslef and outlines (programs) his subsequent route (Figure 13).

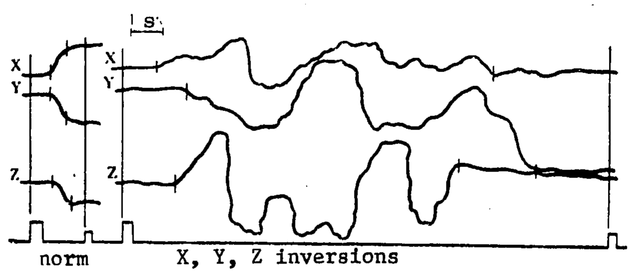

Figure 13. Sample of tracing of the start of formation of a skill with X, Y and Z inversion

In essence, one can count 3-8 complete cycles in the structure of the phase with a move over one matrix element, and each of these cycles consists of its own stages of programming, implementation and checking [control]. In other words, the phasic stage of integral action separated into a number of movements in different directions; and if we consider that such high-amplitude movements in different directions seem to permeate the operational space were recorded for each element X, Y, Z of spatial action, it becomes clear how chaotic and disorganized this action appears, and it cannot actually be called an action, since it is not purposeful and separated. It can be conceived as artificially connected chains of operations, each of which has a specific direction, velocity and point of application. Hence, it is quite obvious that the primordial function of movement--executory--is transformed at this stage of mastering action into a cognitive, exploratory, orienting function.

Thus, a new sensorimotor image of space begins to develop on the basis of active actions that probe the work space in all directions, the function of which is not executory but exploratory. At the first stage of development of the sensorimotor image there is formation of a rather general image of the situation as a whole (Figure 14, Curve 1), which could be called the stage of construction of an image of a concrete situation.

The next stage is characterized by long duration, taking up about several dozen implementations. This stage is characterized by probing motions in the direction of the target (Figure 14, curve 2). Here there are no more wide-amplitude movements in different directions. The movement from one matrix element to another appears to be divided into several successive operations, in each of which one can clearly distinguish programming, implementing and checking stages. The subject appears to quantize the imagined trajectory into small segments, where a build-up in velocity of performing the action is followed by complete stops. And the less the image of the space is assimilated, the more quanta there are. It must be noted that the increase and decrease in velocity occurs separately for each component of movement, X. Y, Z. This indicates that at this stage of assimilation of the image, the action is not planned simultaneously (spatially), but successively, separately for each coordinate. Moreover, it is not planned completely even for one coordinate, but is separated into quanta where the end of the preceding one serves as the beginning of the next.

The single action at this stage is transformed into a chain of successive, probing operations in the direction of the set goal and ultimately reaching it. Such actions are necessary to match the image formed in general features with specific motor objectives. In addition, they are apparently directed toward finding the scalar conformity of hand movement with the location of the matrix element on the screen.

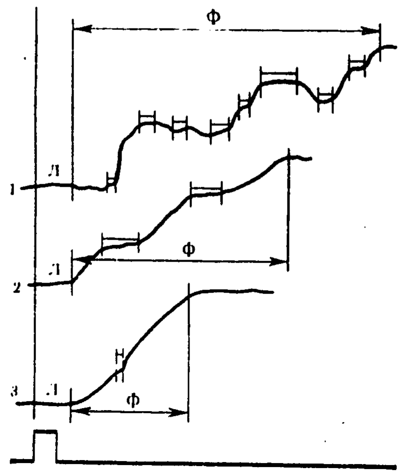

Figure 14.
Diagram of stages of formation of a sensorimotor image of space (the segments of drop in velocity to 0 have been isolated in the phasic stage); Л--latency time; Ф--phasic structure

Thus, the second stage of assimilating the sensorimotor space could be called the stage of construction of the image of real executory actions.

The next stage of the image of sensorimotor space could be referred to the figurative, orienting part of action only at the very first stages of its formation (Figure 14, curve 3). It is characterized by purposeful integral actions, the function of which is essentially directed toward merging of the already formed image of the situation with the image of real executory actions. This function is rather complex; it does not require a mechanical connection, but good penetration of one into the other and, on the basis, construction of a simultaneous sensorimotor image, the only one for the prevailing conditions, of the work space. The executory part of action proper will then be refined on its basis. The presence of such a single orienting image makes it possible for the action program to be formed and perfected at this stage, the first attempts at construction of which had already been evident at the stage of construction of the image of executory actions.

How is a connection of regulatory and executory components, each of which has many degrees of freedom, possible: What is the process of limitation of number of degrees of freedom in both elements of the motor act? These questions arise when analyzing a formed motor act, but they become even more acute with regard to the process of its formation, with regard to the process of man's mastering both traditional and new tools of work activity.

Studies of characteristics of cognitive components, as well as of the process of their formation are of extreme importance, since expressly they relate the orienting and executory components of activity.

Comparative qualitative and quantitative analysis of the characteristics of hand and eye movements made at different stages of mastering motor skills demonstrated general patterns of change in the parameters under study [21]. As the motor skill is learned, there is a reduction both in total time of performance of the action and in duration of each isolated stage of integral action, as well as in duration of the period of oculomotor activity. The duration of the programming stage of action is proportionate to the length and difficulty of the trajectory of movement. When traveling over any trajectory, the latency time of hand movement when changing from the start position to the first reference point on the route is several times longer than the latency time of movement between any other points on this route, and the more complex the trajectory, the greater this difference. The general sequence of phases of hand and eye movements is always the same: after delivery of the signal, a latency period for hand and eye movement is recorded, followed by a period of oculomotor activity; and the more complex the trajectory, the longer the last mentioned period; then hand movement begins.

The eye movements observed in the study were divided into two functionally different classes. The first class refers to orienting-exploratory eye movements that are demonstrable only at the latency stage of hand movement. As the motor skill is formed there is gradual reduction thereof. The function of orienting-exploratory eye movements is to form a perceptual-motor image of space and plan movement over the entire route. The second class refers to afferenting eye movements that are divided into two types: saccades tracking hand movements, and jerks toward the target ahead of the hand movements. As the skill develops, the tracking jerks are transformed into beforehand ones. The function of afferenting movements is to compare, correct and determine the scale conformity of the set program with the real problem.

At the early stages of learning, subjects who do not know how to use the manipulator present many eye movements that intersect the test matrix during the latency period of hand movement. These eye movements are mainly of the back-and-forth type. At the performance stage, these subjects present afferent tracking movements of the eyes, associated with executory hand action (Figure 15).

As skill develops, there is gradual decrease in back-and-forth eye movements. They persist only during the latency stage of the first transition, i.e., before the start of hand movement. This also corresponds to a reduction in latency periods of hand movements over each transition to matrix elements; the first latency period decreases the least. The back-and-forth saccades are transformed into forward-going ones, directly preceding executory action. In turn, with a well-developed skill, the afferent tracking eye movements are transformed into advance ones of executory action. After the advance saccade, the eye fixes on the target until the executory hand action is terminated, i.e., until the controlled spot coincides with the appropriate matrix element (Figure 16).

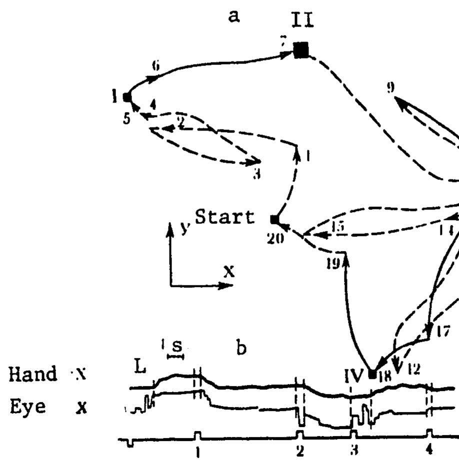

Figure 15. Sample of tracing of eye movements at the first stage of learning action

a) orienting, back jerks in coordinates X, Y of plotter
b) time scan on polygraph; dash line--orienting jerks
I, II, III, IV) matrix elements
1-20) eye fixations
L) latency period

In the course of learning, a new spatial image is formed, and sensorimotor coordinations corresponding to the experimental situation are altered or formed anew; after the sensorimotor image is formed, the program of the action under study begins to form actively. One of the indications of a formed spatial image and spatial action is the type of eye movement, number of eye movements, velocity of hand movements and nature of sensorimotor interaction.

According to the foregoing, in order to understand the process of transformation of the human hand into the "tool of tools" there must be proper theoretical and methodological orientation of studies of executory activity. The movements of a living organ not only must be understood, but disclosed as a sort of morphological object, functional organ. "Any temporary combination of forces capable of making a specific achievement" [58, p 71] is a functional organ. The analogy between movements of a living organ and anatomical organs or tissues was conclusively substantiated by its two most important properties: "... in the first place, living motion reacts; in the second place, it consistently undergoes evolution and involution [7, p 178]. Such interpretation of living movement, distinction of its

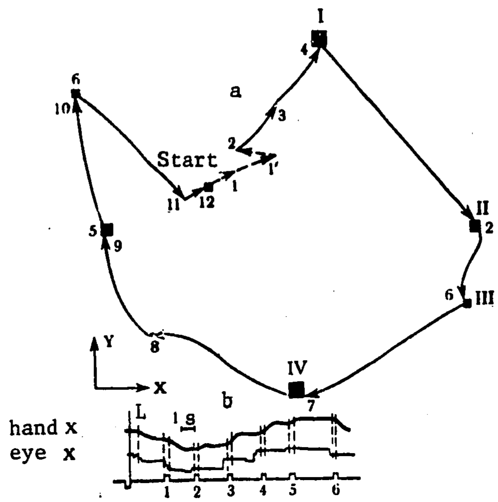

Figure 16. Sample of tracing of eye movements at the last stage of learning an action (designations are the same as in Figure 15)

"biodynamic tissue" as the object of investigation provides a new strategy for scientific study and practical organization thereof. In particular, this also means that movement, the motor schema, skill cannot be assimilated; they have to be constructed by the subject. "Exercise is repetion without repetitions" [7].

It is known that as man learns a specific system of movements it becomes stereotyped. But then, "... this system, which was previously something exogenous, an object to be assimilated, gradually changes into a distinctive organ of individuality, a means of expression and realization of man's attitude toward reality" [28, p 394]. Modern ergonomics is increasingly concerned with the structure of this "organ of individuality," understanding and foreseeing what could be done with its help.

3. Functional Structure of Cognitive Actions

With each year, there is more and more new experimental confirmation of interpretation of mental processes as special cognitive actions formed during ontogenetic and functional development, and practical applications are being found in ergonomics and engineering psychology. Specialization and differentiation of work activity have led to frequent limitation of the functions of a worker mainly to the area of perception, as a result of which processes of detection, identification, recognition, information retrieval, short-term storage and transmission of information, and decision making emerge as independent purposeful actions in the work process. Of course, each such action ends with a specific executory act, i.e., it is part of a broader structure of activity; but since these executory acts are often quite elementary, professional competence can be determined by perceptual or intellectual components. For this reason, ergonomics is referring more and more often to general, experimental and even genetic psychology; it actively formulates and solves new problems that are within the competence of these branches of psychology.

New technological means of activity require the formation of special perceptual abilities, actions and skills. The diverse forms of activity of operator-observers, which appeared in the last decades, illustrate the best the known thesis that human sense organs are the product of all prior worldwide history. The study of these types of activity under real and laboratory conditions has led to accumulation of enormous factual material, which has been generalized in a number of theories and models, the substance of which is that they overcame naturalistic conceptions of human capabilities in general and cognitive capabilities in particular.

There is an extensive psychological literature dealing with functional, structural and genetic aspects of perception, memory and thinking processes. In this section, we shall limit ourselves to a general description of the most important cognitive processes, which play a leading role in work activity, and we shall submit material that may be useful in solving ergonomic planning problems. Special attention will be given to the enormous reserves available in human perception, memory; reserves that may alleviate substantially the solution of complex technological problems if they are used rationally.

In the preceding section, we demonstrated the significance of image of a situation and image of actions, which must be performed in this situation for development of skills. Studies of images and distinctions of their formation are becoming central to cognitive psychology as well, which is successfully overcoming, through the work of its most farsighted representatives [68, 71], the stimulus-reactive and behavioristic schemes that had been used for a long time to analyze behavior and activity.

The concept of image is being to play an increasingly noticeable role in engineering psychology and ergonomic research. The information model of a real situation in man-machine systems must first be analyzed by the operator; he must form his own graphic-conceptual model of the situation, make a decision and only then perform the executory action. This example clearly demonstrates the inadequacy of explanatory stimulus-reactive schemes. There is dual likening to reality, or two images, two models of reality between action and reaction in the activity of an operator. Each requires specific cognitive actions by the operator, which are performed both externally and internally.

Purposeful action can no longer be implemented on the order of immediate servicing; it is performed according to schemes of deferred servicing or, more precisely, active action; there is repetition and transformation of phenomena into an information model in the interval between action and reaction; this model is obtained by technical means; repetition and transformation of phenomena in the graphic-conceptual model are obtained by psychological means.

Information and graphic-conceptual models emerge as synthetic elements that disclose to man space that is accessible to comprehension and action of the world. Of course, graphic-conceptual and information models are not identical, but the description thereof in similar terms alleviates substantially the task of synthesis of man-machine systems.

It is useful to discuss the most general properties of visual images in order to comprehend processes of formation of graphic-conceptual models, as well as transformation processes that are performed for information processing and decision making.

Images are subjective phenomena that arise as a result of object-related practical, sensory-perceptual and thinking activity in both the presence and absence of adequate sensory stimulation. An image is the integral, whole reflection of reality, in which there is simultaneous representation of the main perceptual categories (space, motion, color, shape, composition, etc.), and, as is well-known from psychology of perception, the effects of these categories on the observer are not independent. The most important function of an image is to regulate executory acts. It is logical to conceive that a regulator is just as real as an actuating mechanism and that it has the same properties as the regulated object. In the preceding section we submitted arguments in favor of consideration of living motion as a special functional organ having, by analogy with morphological organs, the properties of reactivity and sensitivity, which are governed by the laws of evolution and involution.

It is not difficult to detect analogous properties in cognitive processes as well.

Perception, memory and thinking are also actions (or systems of actions), each of which undergoes reactive evolution and involution [28, 30, 41]. The results of these actions are first fixed in images (motor, perceptual, mnemic, mental) which, in turn, perform regulatory functions with regard to subsequent occurrence of cognitive and executory acts. We always localize images of real objects in external space, where the objects of perception or action are.

The same applies to visualized images, representations, which the observer sees in the absence of the object of observation. An image does not exist as a certain subjective datum outside the process of objectivization, exteriorization. Thanks to the localization of an image in external, three-dimensional space (including its analogs transformed by the subject [73, 74], it is possible to regulate executory actions performed externally. In other words, regulation of executory acts is possible only through the subject-related [subjective?] environment, reflected in the objectivized image.

A distinction is made between two types of structures in visual perception: spatial, which is related to localization of the outside world in the coordinates of three-dimension space, and structure of proximal stimulation, which is related to the anatomical coordinates of the retina. It is possible to demonstrate the relative independence of these structures from one another in special studies, although they are interrelated in a real act of perception. Both structures are also characterized by certain iconic (pictorial) properties [79]. The iconic properties of these structures constitute the sensitive fabric of the image (and consciousness) which is usually fused with the tangible content of perceived reality [48], i.e., it is localized in external three-dimensional space. It is expedient to continue the discussion of image properties in terms of biodynamic and sensory tissue, although this separation cannot be absolute, since there are iconic, sensory properties in biodynamic tissue of movement (see Section 2). The spatial structure of an image is formed as a result of tangible [object-related] actions of the subject, by virtue of transformation of biodynamic tissue of movement into the sensory tissue of the spatial image. This applies not only to the process of formation of an image, but to the formed image; for a halt can be interpreted as accumulated movement, a simultaneous cast thereof. A form of biodynamic tissue of movement is present in both the generated and embodied image.

As a spatial image is formed, it is filled with tangible properties, imbued with sensory tissue and, with it, is localized in external space. This applies to both sensory tissue that is related in origin to biodynamic tissue, and sensory tissue related to the iconic properties of proximal stimulation. The latter is also exteriorized and fused with the spatial structure of the image. After such fusion, the image emerges as an integral, indivisible whole.

Consequently, both sides of the same whole appear to be represented by biodynamic and sensory tissue in the formed image. Moreover, they become reversible. Biodynamic tissue of movement, action, plays the leading role in formation of a spatial image. In the formed image, the leading place is occupied by sensory tissue, including that originating from proximal stimulation. The reverse occurs in construction of movement, i.e., the sensory tissue of the image is transformed into the biodynamic tissue of movement. Ultimately, movement is, so to speak, the substance, the shell of the image. But if the thesis is valid that activity dies in the product, it should be just as valid that the image dies, is embodied in activity in order to be reborn as a result of its completion. For expressly this reason images have the property of openness. The sensory tissue of a spatial image, which is related in its origin to the subject's active movements in the outside world, can emerge as a regulator of executory actions. Performance of the latter again leads to transformation of biodynamic tissue into sensory, to expansion and fixation in the image of more and more new properties of tangible reality. However, very often the formed detailed image of the surroundings is too superfluous to solve utilitarian problems of regulating executory acts, although it is, of course, necessary to decision making as to the purposefulness of some action or other. Transformation of the spatial image, of its biodynamic tissue, into a more or less automated scheme is a means of overcoming superfluousness in stereotyping and standardizing the conditions for performing action. In the schemes that are formed as a result of such transformation, then in the symbols, there is amplification of elements of abstraction and, consequenlty, a decrease in share of biodynamic and, particularly, sensory tissue.

The foregoing leads us to the conclusion that images, just like movements, should be viewed as functional organs for regulation of behavior. This interpretation of an image as an organ of individuality ensues from the views of A. A. Ukhtomskiy, who considered the dominant as a special functional organ. He wrote about its external and internal expression [58]. Stationary performance of work or working pose of the body is referable to the external expression of the dominant. The internal expression refers to experiencing the dominant in the form of an abbreviated symbol ("psychological recollection"). B. G. Anan'yev, who also stressed that the whole, or integral image can be viewed as a distinctive organ of behavior, called attention to this aspect in the works of A. A. Ukhtomskiy. Such a single interpretation of movements, images and sets as functional organs of individuality makes it easier to demonstrate the correlations existing between them.

Each man has numerous images of the most diverse spaces: rooms, streets, cities, favorite painting, etc. Some of us can find our bearings well in microscopic space and even in outer space, and unquestionably there is a capacity to readily move from working in one space to working in another space. As a rule, images of the surroundings also include the "body schema." Body schema is man's general conception of his body, its outline and dimensions, boundaries, orientation and movement in surrounding space. F. D. Gorbov [17] observed that as man continuously changes the position of his body he concurrently creates and tests the postural model that forms the body schema. The perceived boundaries of the body schema are extremely mobile. The body schema includes clothing and diverse work tools (pen, shovel, car, tanker, etc.). A vivid example of the spatial properties of images are the phenomena experienced by amputees of movement of phantom limbs, when the stump does not really move.

These examples are indicative of the gradual shifting of the individual's sensitivity into external space, of the individual's development of increasingly adequate and complex spatial images and models of reality. Of course, depending on the objective of activity, reflection of physical space in subjective images may be transformed. It may be perceived in direct and reverse perspective, deliberately reduced or extended, schematized, etc. The description of subjective images, conceptions and actions in terms of time and space properties is no more arbitrary than the description of DNA in the form of a double helix. It is not by chance that specialists in the field of industrial psychology and planning ergonomics have long since operated with such terms and concepts as motor field space, time and space properties of motion and perception, graphic-figurative schemes, which guide man's activity in the work space. They also use such terms as operational unit of perception, image-manipulator, which bears a reflection of reality, as well as its interpretation and plan of action.

Not only space, but time are reflected in visual images. There are elements of the present, past and future in simultaneous pictures ("arrested moments"). Reflection of time in images is based both on mechanisms of perception and extrapolation of movements and mechanisms that are similar to the semi-transparent file of traces fixed at different points in time. On the one hand, this permits perception of the world as stable and, on the other, consideration of past, current and future changes in it. Consequently, visual images permit potential and actual reflection of reality with all the wealth of both visible relations between objects and latent ones at a given time.

Reflection of time in images is the basis of phenomena that are described in terms of "foreseeable future" (N. A. Bernshteyn) and "acceptor of results of action" (P. K. Anokhin).

It is an extremely difficult matter to create an adequate conceptual system to describe the structural and functional features of time and space schemes and constructions present in images, since they are usually concealed, not only from external observation but introspection. In ontogenesis, the basic perceptual categories that form the foundation for subjective [object-related] meanings are virtually learned prior to development of processes of verbal communication, within the framework of which there is initial formation of symbolic knowledge of the world. As the powerful system of voluntary regulation of activity, which is speech in adult man, develops the impression is gained that processes of graphic-figurative reflection begin to play a subordinate role. It must be stressed that, at the stage of fully developed verbal communication, perception (and content of the image) is not identical to the process of reference to some arbitrary categories or other.

With respect to information, images are an exceptioanlly capacious form of representation of reality. There is room in them for information about time and space, dynamic, color and figurative features of objects. They are multidimensional, multicategorial, as well as multimodal. The images reflect not only basic perceptual categories, but correlations between them, both within one category and in intermodal correlations. Hypotheses have been expounded to the effect that graphic images are readily transformed into amodal images, perceptual or tangible concepts--complexes ("diffuse concepts"), etc. In other words, images are multilayered, both genetically and functionally, which enables man so to speak move into the realm of symbolic meanings and concepts, to reflect on the upper layers of the image of the world he has constructed, to deliberately operate with signs, symbols and words. As for basic perceptual categories, although they do serve as guidelines for man's practical activity, they seldom become the subject of reflection. Of course, man continues to make effective use of graphic-sensory, figurative reflections of tangible reality, but mainly in a discrete, latent form.

Just like the different aspects of complex motor acts are implemented by the coordinate function of different levels of construction of movements, the perceived spatial localization of objects and description of their shape are, according to the results of special studies [11], products of information processing on different levels of construction of the image. In perception, just like in regulation of movements, primarily the object-related content is recognized, which corresponds to the meaning aspect of the task confronting the subject. Background coordinations, implemented at lower levels, are not represented in the focal area of consciousness, even when dealing with such processes as reflection of brightness features or movements of an object. This latency of perception, which is beneficial to the subject, does not relieve psychology of its quite conscious consideration, the task of reconstructing this amazing world of mental reality, of the search and development of objective and, at the same time, psychological methods of studying it.

Reconstruction of background coordinations on the lower levels of the process of formation of a tangible image is particularly important, since objects, situations and events are represented in coded form in information models. There are not uncommon cases when the most informative signs of reflected objects are encoded by distribution of brightness, movement, while the spatial features of objects are coded as alphanumeric information or points and lines on the plane of the means of display. In such cases, operators have to reconstruct the situation on the basis of input information that is known to be sparse and often distorted. In other words, the background, unconscious levels of operator activity become the object of special perceptual actions, and it is only on their basis that the tangible image of the reflected situation can be formed.

Studies of operator work show that reference of information the operator receives to real objects is often done as a quite conscious action, which causes certain difficulties and is not easily exercised or automated. M. L. Gallay wrote about these difficulties: "I can imagine how the pilot's glance darted from instrument to instrument during this turn: bank, acceleration, velocity, climb, bearing, bank again, velocity again.... Inertia causes the body to adhere tightly to the seat.... He is trembling from the strain of the aircraft.... Beyond the steamed windows of the cabin is nothing but milky darkness, but the pilot sees, with the inner vision developed over years of flying, what a clever curve, on the very border of what is feasible, his craft is describing." In this description, we are impressed, in the first place, by the fact that the pilot does not see the instruments as he does the trajectory of his craft in space and, in the second place, that this vision is the result of the function of internal vision developed over years of flying. This example is not an exception. There are many occupations, the main content of which is the perception and recognition of visual images, their interpretation and processing. Decoding aerial photographs, photos in tracking chambers and x-rays may serve as examples. Specific problems arise when organizing man's activity under such conditions, which alter appreciably the characteristics of sensory and perceptual processes, for example, visual perception in space without landmarks, perception in weightlessness or in the presence of distorting media. Although this may sound paradoxical, perception, which seems so natural and spontaneous, is a serious and sometimes very difficult job. The complexity of many professions related to information receiving and processing is referable to the fact that one has to detect clear and distinct signs of specific physical events in a confused and vague picture, i.e., construct an image of these events with tangible significance, which could then be converted to symbolic, verbal form.

Visual images have an enourmous capacity for information. As compared to auditory and motor images, they are characterized by subjective simultaneousness, which permits instantaneous "grasp" of the relations between elements of a real or imagined situation. Simultaneousness characterizes not only perception of real objects, but reflected ones, including those that are coded. For this reason, the use of multidimensional codes (combinations of color, shape, configuration, etc.) does not increase perception time, as compared to one-dimensional codes [42].

Images have a greater associative force than words. For this reason, it is possible to store images well in memory. After single presentation of several thousand pictures, observers are capable of correctly recognizing about 90% [12].

In addition to reflecting reality, visual images have intentional and affective components; for this reason, regulation of behavior and activity by means of an image is remarkable in that it allows for a certain degree of activity that is independent of the immediate external situation. In other words, the images are subjective and biased. There are also operational components in images, since their origin is related to action. The presence of operational components enables images to become transformed into perceptual-motor schemes and perform the function of regulating behavior, with due consideration of external circumstances, as well as motivational and goal-related aspects of activity.

The next group of properties is related to their lability and flexibility. These properties are manifested primarily by the fact that rapid transitions are possible from a general evaluation of a situation to detailed analysis of its elements on the figurative plane. They implement diverse spatial discplacements of objects reflected in the images, changes therein, turns, as well as enlargement, reduction, perspective distortion and normalization. This distinctive manipulative capacity of the visual system [36] makes it possible to represent a situation in both direct and reverse perspective. Image manipulation serves as the means of solving recognition problems, it makes a certain contribution to mechanisms of consistency of perception, and it is also a most important means of productive perception and visual thinking [40, 64, 73]. Collision or combination of different images may serve a meaning-forming function. As we well know, the degree of control of image manipulations may vary significantly.

Productive manipulations of images are the most effective when they occur either in the absence of an object of observation or when there is detachment from the external situation. Visualization and manipulation of images on the level of graphic representation interfere with perceptual work directed toward external reality and, to a lesser extent, they interfere with processes of pronunciation, inner speech. This creates a possibility for parallel recording of results obtained from work with images in verbal meanings. Incomplete, partial images, in which there is an element of something "unfinished," impairment of equilibrium, tension, etc., are induced more by the manipulative capacity of the visual system than completed images.

Studies of manipulative capacity of the visual system lead to the conclusion that a formed image is a multifunctional organ of behavior. In it is fixed the multilevel reflection of reality; it is the regulator of executory acts and, at the same time, emerges as the "subject" of reproductive or productive activity and, finally, as its product. Of course, images that are formed as a result of tangible, practical action differ from those formed as a result of perceptual actions. The same applies to images formed as a result of mnemic or mental activity. There are also differences between images formed in the process of learning [examining] and those that regulate executory action. Although they have a very close relationship to one another, their content, completeness, level of generalization and other features are different. These properties of images depend on the problem being solved by the subject and the methods he uses, i.e., the nature of perceptual actions used by the subject.

Development of perception leads to the acquisition of new quality to both the image of one's own body and images of objects in the outside world and they can become part of the linguistic, semantic space. Images and the perception process as a whole become accessible to reflective analysis. Along with perception of the object there is awareness of its functions, thanks to which perception becomes generalized and categorized. Verbal generalization permits drawing upon complex semantic associations established in language for analysis and distinction of the aspects of the perceived object that would have otherwise remained inadequately perceived. Objectivization of images permits "running through" variants of behavior and activity on another substrate, the substrate of reflection, model, image, before performing executory actions on the real substrate.

This, of necessity brief, description of visual images confirms the previously expounded thesis that the study of processes of receiving and processing information without consideration of the enormous informational, cognitive and creative potential contained in the tangible-practical and sensory-tangible* forms of reflection of reality could lead to a drastic underestimation of man's actual capabilities for perception and information processing. Man has realy inexhaustible reserves for increasing the "carrying capacity" of perception. It is only a matter of properly utilizing these reserves, i.e., creating external means of activity designed for the strong points of cognitive processes, and not the weak ones.

Processes of image formation, recognition and operation take place by means of special perceptual actions.

Perceptual actions: According to current conceptions, perception is an aggregate of processes that provide for subjective, biased and, at the same time, adequate reflection of reality. The adequacy of the image is not a given from the start, it is achieved because as the image of perception is formed there is comparison of perceiving systems to the properties of the stimulus. With regard to place in the structure of activity, perceptions are usually actions, with the exception of cases when the creation of an adequate or new image constitutes an independent motive. The requirements made of perception by practical activity are called perceptual problems. To perceive means to solve some perceptual problem by creating an adequate reflection of the situation; for this

*Translator's note: Tangible, i.e., related to an object.

reason, perception is a system of perceptual actions. Perceptual action consists of various operations and functional units. Perceptual action is an active, dynamic process regulated by the objectives of activity, which has feedback and anticipation mechanisms and is governed by the distinctions of the object examined. The activity of perception consists primarily of participation of effector components that emerge in the form of movements of receptor systems and displacement of the body or parts thereof in space. These movements are divided into two major classes. The first refers to searching and setting movements, by means of which a search is made of the specified object, the eyes are set in the most convenient position for perception and change in this position. The same class includes head movements in response to an abrupt sound, tracking movements of the eyes, etc. Such movements not only create optimum conditions to perceive an object, they also participate in determining its spatial position.

The second class consists of actually gnostic movements. They are directly involved in estimating dimensions, recognition of familiar objects and, finally, the actual process of construction of the image. There is continuous comparison of the image to the original in the hand movements probing an object and eye movements tracing the visible outline. If these do not correspond to one another, there is correction of the image. Consequently, the role of the motor system in perception is not limited to creating optimum conditions for the function of afferent systems, and it consists of the fact that movements themselves are involved in formation of a subjective image of the objective world.

In order to determine in greater detail the role of perceptual actions in formation of an image, it is expedient to use the line of reasoning that is analogous, to some extent, to the one used by N. A. Bernshteyn to define the role of sensory corrections in regulation of human movements. Because of the many degrees of freedom of objects around a subject, as compared to what is perceived by him and the infinite diversity of conditions under which they appear, they constantly alter their appearance and face us with their different sides. In other words, no sensory impulse or stimulus alone can unequivocally determine the appearance of an adequate image of perception. Here, a correction is needed to rectify inevitable errors and it causes the image to conform with the object.

However, if such an image is materialized only in internal processes of the body (states of the receptor and cortical end of analyzer), it would be impossible to compare it to the original and, consequently, the necessary correction could not be made. Consequently, there must be exteriorization of the reflective process, and this is what occurs in the form of perceptual actions. Just like motor behavior of an individual can comply with the problem conditions only by virtue of sensory correction, so the adequacy of perception is ultimately assured by effector correction.

In general, the physiological scheme of activity (no matter whether we are dealing with the scheme of the reflex arc or reflex ring) cannot "contain the object in itself" with its specific tangible properties is the broader aspect of this problem. Within the framework of this scheme, the object can only appear external in relation to a given process, as a stimulus that has to be recoded into a series of nervous impulses. For the object to be included in the system of human activity, we must go beyond the boundaries of its physiological description and consider it psychologically as external, purposeful activity of the individual. The latter contains the object with all its specific distinctions as its own organic component. This applies in full and primarily to work tools, which are contained in man's "body schema" to such an extent that sensitivity is transferred to their boundaries.

Special training and rather long practice are required to master the system of perceptual actions. It is important that both perceptual actions themselves and the criteria of image adequacy do not remain unchanged, but undergo a considerable process of development, along with development of activity itself.

The process of image formation consists of a series of perceptual actions, such as detection, isolation of informative signs consistent with the tasks of activity, examination of isolated signs and actual construction of the image. Perceptual actions are seen in their expanded external form only at the early stages of ontogenesis or functional genesis, when the observer encounters perceptual content that is new to him. In such cases, there is the most distinct demonstration of their structure and role in formation of images of perception.

Thereafter, they undergo a number of successive changes and reductions, until they take on the form of an instantaneous act of "perceiving" the object, which has been described by the representatives of gestalt psychology and mistaken by them for initial, genetically primary form of perception.

The most important property of perception is the ability to alter perceptual images and models of the outside world and possibility of changing the means of constructing and recognizing them. The same object can serve as a prototype for many perceptual models. They are refined in the course of their formation, invariant properties and signs are extracted from the object and this ultimately leads to perception of the world as it really is. The diversity of possible perceptual images of the same situation or object is attributable to the fact that external perceptual actions, like executory actions, contain the reflection of the motor problem. Involvement of differently organized movements and actions in perception processes is also the basis for explanation of subjectivity and bias of perception. In the course of development of perceptual actions, there is also formation and development of their cognitive products, which include sensory and perceptual standards, operational perception units, schemes, images, etc.

Formation of sensorimotor standards play a most important role in perception; they do not correspond to isolated properties of reality, but to systems of socially developed sensory qualities [29]. They include the generally recognized scale of musical sounds, "phoneme grid" of the native language, system of geometric forms, etc. While sensory standards are the result of sociohistorical endeavors of mankind to isolate and create systems of sensory qualities needed to get one's bearings in the world, the result of man's individual activity to learn the sensory standards is called operative unit of perception. The operative units of perception are compact, semantic, integral elements formed as a result of perceptual (including occupational) training, and they make it possible for virtually instantaneous (simultaneous, one-act) integral perception of objects and situations, regardless of the number of tags [signs] they contain. Concretely, operative [operational] units of perception emerge as the content extracted by the individual when performing some perceptual task or other. Development of perception is related to change in operative units. As shown by studies, this change is manifested by the transformation of groups of random, special tags into structured, integral ones [32, 61]. Concurrently, there is also a change and refinement of perceptual actions themselves.

Whenever an individual encounters a reality that is new to him, or when a previously formed image turns out to be inadequate, the perception process again changes from simultaneous to successive, and it occurs by means of expanded perceptual actions.

There are special recognizing actions in developed processes of perception. They are used to single out the informative content, from which the observer can compare the presented object to already formed operative units of perception, identify it and, finally, refer it to a class, i.e., categorize it. Recognition takes considerably less time than image formation. It is enough, for comparison and recognition, to isolate in the object only some typical, informative signs. This is feasible because prior experience in active organization of perceptual action, i.e., well-learned "schemes" for examining an object, has been accumulated in operative units of perception. These schemes emerge as an aggregate of rules or general motor programs intended for singling out the important aspects of what is "typical" in a given class of objects. These properties of operative units of perception are the basis not only of processes of examination and identification, but of generation or visualization of the image, which occur in the absence of a physical stimulus. Such interpretation of operative units of perception is similar to the schema theory of F. Bartlett [65] and the concept of "general efferent readiness" of the individual, which is central to the motor theory of visual perception expounded by L. Festinger et al. [69]. According to this theory, conscious visual perception of the outline of an object is determined by the "efferent readiness" of the individual to perform specific movements of the eyes, hands, head and trunk in response to incoming visual information. Efferent readiness refers to the agreggate of preprogrammed efferent instructions (motor programs) that are activated by visual information and are in a state of readiness for instant use.

Efferent readiness, actualized by a stimulus, may be related either to deployment of perceptual and identifying actions, or implementation of adaptive, executory actions. In the latter case, efferent readiness accelerates performance of executory acts and could serve as the source of erroneous action.

To return to the description of operative units of perception, it must be stated that they reflect not only the subjective aspect of perception, but objective characteristics of problem conditions, possible strategies and means of solving it. They have a reflective component (sensory tissue, perceptual meaning, etc.) and a dynamic, operative component (efferent readiness for further deployment of perceptual actions directed toward more complete formation of image of the situation, readiness for visualization and even performance of executory actions in familiar, simple situations). This means that there may be fusion of perceptual meanings and efferent readiness to actualize generalized motor programs in the operative units of perception.

The sensory standards, like the operative units of perception, should be viewed as certain tools, instruments for perceptual and identifying actions. The standards mediate these actions just like practical (labor) activity is mediated by a tool and thinking, by words.

Development of perception leads to the creation of a rather vast alphabet of operative units of perception, i.e., a certain set of schemes, perceptual models of the environment. While at the phase of image construction and transformation there is comparison of perceptual systems to the properties of the stimulus in the operative units of perception, at the phase of recognition or executory action there is substantial change in characteristics and direction of the process on the basis of the formed operative units of perception. These changes consist of the fact that the individual no longer only recreates the image of an object by means of perceptual actions, but records, translates the information received into the language of operative units of perception or perceptual models that are already known. In other words, concurrently with comparison [likening] of the perceptual systems to the object, there is likening of the object to the individual, and only this two-way transformation leads to formation of a complete, adequate and, at the same time, subjective image of objective reality.

The foregoing indicates that perception processes are active, historical and object-related. The last quality of perception emerges in the form of integrity, constancy and meaningfulness of the perceptual image. Perception is integral, since it reflects not the isolated qualities of stimuli but the relations between them. The integrity of perception is closely related to its constancy, which refers to the relative independence of perceived characteristics of the object from projected characteristics of their reflections on the receptor surfaces of sense organs. Active perceptual actions serve as the source of constancy. The relatively invariant structure of object properties is singled out of the variable flow of stimulation by means of perceptual operations. The operative units, which are formed under the most diverse conditions, permit active consideration of changes in projection properties of the object and compensate for them. As this is done, the reflection of the object remains unchanged both in relation to movements of the object and movements of the observer. Consequently, changes in projection properties of the object may even be necessary to retain constancy.

As we have mentioned, the visual system has a very distinct manipulative capacity which, like external perceptual actions, is derived from practical, tangible actions. One of the most important problems that are solved with these perceptual mechanisms is counterchange in operative units of perception to compensate for changes in stimulation from an objectively stable object. The ability to manipulate an image enables us to perceive as stable and constant objects that are seen at different angles, from different distances, as well as when there is a relative shift in the field of vision due to eye movements.

Manipulation of image and operative units of perception occur by means of a special class of perceptual actions that were named vicarious. Various sections of a successive image are analyzed by means of vicarious eye movements. Typically enough, vicarious eye movements are observed after tachistoscopic display of images, which is too brief for any searching eye movements. They are also observed when an image is stabilized in relation to the retina, in dreams, when imagining an object in its absence, when working with visualized images, etc. In the last cases, they serve to analyze and transform visual images. Vicarious perceptual actions replace action with real objects, anticipate and plan them. Evidently, the mechanism of vicarious perceptual actions consists of selective change in sensitivity of different parts of the retina, which is controlled by low-amplitude eye movements. These movements are made in the 2-5° zone, and they are in the form of either drift or rapid saccades. This mechanism has been named the functional fovea mechanism [36].

Depending on the complexity of the task, prior experience of the individual, including the operative units of perception consistent with the task, performance thereof may require various perceptual actions:

detection, identification, recognition, information retrieval, etc. In turn, each of these actions may be performed as a more or less complete part of perceptual operations. For example, visual estimation of distance is possible through consideration of many different signs of distance to the object (disparity, monocular parallax of movement, differences in angular dimensions of close and distant objects, height, position of the object in the field of vision, etc.). Different signs are used, depending on observation conditions; and although the concrete perceptual operations are different in each case, the result--formation of an idea about distance of the object--is about the same. The same applies to perception of form, which is possible by means of both touch and vision. Recognition processes may occur as single, simultaneous actions or acquire an expanded form of comparison of different signs of the object to those of the standard.

Even the detection process, which, it would seem, occupies the initial position in the system of perceptual actions, may consist of expanded processes of information retrieval, identification, comparison and recognition. In other words, in each individual case, there is actualization or formation of a functional structure of perceptual actions and operations consistent with conditions of activity, depending on the task, the tangible content of activity and experience of the observer.

In solving many scientific and, particularly, applied problems, one often encounters situations that are beyond the "resolution capacity" of analysis of macrostructure of cognitive processes. This applies entirely as well to perception, which emerges most often as an operation in everyday life and occupational activity. Of course, it does not cease to be a complex mental process. The terms simultaneousness or "in one act" are no more than epithetics that conceal [mask] the true complexity of formed perceptual actions. For this reason, in order to comprehend and optimize perceptual processes, we need the means for microstructural analysis, self-styled probes, with which it would be possible to examine highly productive, though brief, mental processes. In other words, for many practical tasks, we need to use and develop principles of analysis of microstructure of activity, which would yield a detailed description of perceptual actions and operations, and, what is equally important, would define the nature of coordinations formed between them. This applies both to perception of the tangible surroundings (including analysis of phases of perception on a real time scale--microgenetic aspect of studying perception) and to the study of processes of reception, storage, use and reproduction of graphic, symbolic and other types of information.

Let us first consider the situation of microgenesis, i.e., actual inception of the visual image of an object. Three or four phases in this process were demonstrated in numerous traditional studies. In the first phase, the answers of the subjects were characterized as: no perception, diffuse background, vague feeling of presence of a shape, etc. At the second phase: amorphous shape, presence of lines, some details (without general, adequate recognition), simplified shape (as compared to the one presented), false hypotheses, general form (without details), addition to what was perceived, etc. At the third phase: recognition, certain perception of shape, clear gestalt, optimum perception of shape, identification, interpretation, etc.

In all these instances, the investigators deliberately made recognition difficult by reducing contrast, increasing distance and eccentricity of the position of the object in the field of vision, etc. In one of the studies of microgenesis of perception conducted in the context of microstructural analysis, not only qualitative, but quantitative characteristics of the process were obtained. B. M. Velichkovskiy succeeded in reconstructing the timing of microgenesis of object perception in sequential and even metric form. He considered three classes of perceptual problems. The first included processes of localization of an object in three-dimensional space, as well as estimation of its dimensions. About 50 ms are spent on solving such problems. Solving problems of the second class is related to the possibility of estimating the sequence of events in time, which requires about 100 ms with intramodal and intermodal combinations of stimuli. This class includes processes of perception of brightness and parameters of object movement. These types of perception are invariant with respect to spatial position, and visible brightness is so also with respect to time of presentation. Finally, the third class of perceptual problems includes processes of perception of the shape of objects. For 100-150 ms from the time the sitmulus is delivered, the object is shapeless and a rather labile structure in perception; 200-300 ms are needed for the shape to be perceived as an unchanging whole, that retains the mutual location of its parts during diverse movements, inclinations, turns of objects in space. Time of perception of a rigid form depends on velocity of movement and complexity of shape, which is approximately proportionate to the number of elements in shape and randomness of their arrangement [11, 14].

In the most recent works of this author, it was demonstrated that two independent stages can be clearly distinguished within processes of perception of figurative features of objects: at the first, more rapid stage, there is evaluation of general outlines, in particular, orientation of the object in space; at the second one, evaluation of specification of internal details of the object. Involvement of focal attention is required for completion of the second stage. Thus, visual perception advances from localization of quasi-object areas in space and time to subsequent description of the general features of these areas and, finally, to distinct perception of the object with all the diversity of its details.

All this enables us to refer to different levels of construction of the image of an object. The process of microgenesis is the successive climb from level to level regulated by a perceptual or any other problem, as well as the time and energy conditions of stimulation [14]. As this ascent progresses, more and more new systems of functional units, operations and perceptual actions are involved in perception. These data justify our returning to the problem of perceptual and verbal meanings and categories discussed above. With visual perception, the minimal lag in verbal categorization is 250-300 ms. In this time, perceptual categorization of data on localization in three-dimensional space, parameters of movement and shape of the object is concluded. It is easy to see that, with integral perception of objects on this time scale, verbalization of all the extracted perceptual information is impossible. It must also be borne in mind that each of the perceptual categories has its own metrics. Apparently, our short-term memory sets the limit of verbal categorization. If it does occur, it is only with regard to the most recently (on the microgenetic scale) isolated perceptual category. Of course, with the appropriate set, the observer can render any of the above categories the object of purposeful perceptual action. Its result will be verbal categorization. The presence of the others can also be fixed in verbal form, but the accuracy of their absolute evaluation will be substantially lower than the category that was the object of special, expanded perceptual action.

There are data indicative of the fact that the sequence of phases implementing the microgenesis of perception may be quite labile. Depending on the individual's problems and sets, microgenesis may not undergo all of the stages and end at any of them. Depending on the same circumstances and properties of stimulation, some of the stages may not participate in the perception process. For example, on the basis of studies of microgenesis, the hypothesis was expounded that aconstant perception is normal perception, in the microstructure of which certain narrow-level operations of evaluation of object position in three-dimensional space have been "wrapped up" [or reduced]. The type of perception that is generally called impressionistic is also attributable to incomplete microgenesis. This mode of vision holds a much larger place in both everyday life and occupational activity than attentive, thorough examination. We often look on a broad field of vision, "without allowing" microgenesis to terminate with distinct perception of an individual object. The adaptational meaning of this mode of perception is that the perceptual systems are open for reception of expected or urgent information. Studies of microgenesis of perception are presently being conducted on a rather wide scale. On their basis, it is possible to optimize processes of control of various transport systems, when man deals not only with displayed information, but must be guided in real space among really moving objects.

Researchers arrive at the conclusion that the fullness of microgenesis is determined by a perceptual or practical, etc., problem. For example, in the course of formation of the image of an object in order to then recognize or remember it there will be distinction of various features. But if it is necessary to make a decision concerning the purposefulness of some action or other, the isolated signs may be quite different from those used for mnemic problems. It is expressly for decision making that it is necessary to form an integral, objecitve, constant and categorial image of the object or situation. But this image, which is necessary for decision making, has considerable limitations with respect to regulation of forthcoming action. It has to be transformed and altered in the interests of the action. This change proceeds in the direction of its decomposition and disintegration, distinction of different perceptual categories in it, such as space, motion, real (and not constant) size, shape, etc. And each of these categories must have an adequate reflection in motor programs. It is quite likely that the microgenesis of perceptual categories observed in the course of image formation, its composition, differs from the order of isolation of perceptual categories involved in construction of action. Nor is reverse microgenesis, or reverse evolution of the integrity, in the course of decomposition of the image and formation of motor programs.

Consideration of this real difficulty requires rejection of a simple linear chain: perception, decision, action, verification [control]. In broader structures of activity that include these components, it is difficult to unequivocally pinpoint a given component. New experimental and conceptual means of analysis are needed to describe them.

Microstructural analysis of cognitive processes: In order to render more graphic the problem of studying congitive activity by means of microstructural analysis, let us start with a description of a real case, which one of us witnessed. A grand master involved in psychological tests was shown a complex chess position to remember for 0.5 s. The chess player refused to reproduce the position, stating that he could not remember anything, but he added that the position of the white men was weaker. In this example, we are amazed by the fact that the subject extracted the meaning of the situation and made an integral (most often flawless) evaluation of this situation without comprehensive, detailed perception, let alone remembering the elements of the complex situation. Such brief, productive mental processes, which create the impression in self-observation of absolute ingenuousness, have long since attracted the attention of scientists. They were named "unconscious conclusions," "contemplation of essentials," "pure datum" ["dannost'" ?], etc. At the present time, interest in such phenomena is significantly stimulated by the engineering psychology aspect of studies of processes of receiving and processing information, and particularly studies of preparation of information and decision making. Demonstration of the structure of short-term processes will help in better planning of external means of operator activity, in particular, information models, as well as in more purposeful formation of internal means of activity.

Microstructural analysis of cognitive and executory activity consists of the study of short-term perceptual mnemic and thinking processes. With the method of microstructural analysis, the latter can be viewed as morphological objects with a fully developed functional structure, specific objective [object-related] content and semantic load.

Since microstructural analysis is intended for the description of the structure of cognitive and executory actions, its most important tasks are to isolate components (units of analysis) that have retained the properties of a whole, and to determine the types of correlations or coordinations that develop between them. The set (alphabet) of such components must be broad enough to cover the process as a whole; in addition, each of these components must have not only qualitative, but quantitative certainty. Microstructural analysis works with the concepts of operations and functional unit. The latter are rather elementary units of conversion of input information. Each functional unit differs from another in a number of parameters, the most important of which are: place in the structure of the operation or action, information capacity, information storage (conversion) time, form of representation in it of some objective content, type of transformation of information and possible connections with other functional units.

The method of studying microstructures is based on isolation, analysis and quantitative evaluation of factors that affect action performance time under various experimental conditions. These factors have the characteristics of external and internal means of activity, which are related to the distinctions and objective content of test material, prior experience in cognitive or practical action. The following is the most popular procedure of microstructural analysis. The time from the start of presentation of test material is divided into a series of intervals, and it is assumed that some conversions or other of input information, made by means of certain functional units or a series of units, occur within each such interval. This preliminary model is submitted to experimental analysis, even in the case of using the same test material (there are provisions for varying the conditions of its presentation, types of instructions and subjects' responses). Then, on the basis of analysis of the results, a more refined model is constructed, which consists of functional units, each of which performs one (sometimes more) function of storage, retrieval, conversion of presented information. In turn, this hypothetical model is then submitted to comprehensive experimental verification, etc. Of course, in such a study, individual functional units cannot be the immediate object of investigation. The object is the integral action of the individual. However, variation of the problems, test material, amount thereof, speed of presentation, type of response actions, etc., which are based on modern methods of planning experiments, permit isolation in this action of individual operations and functional units. Microstructural analysis is a variant of analysis of levels. Accordingly, its most important task is to determine the structure of converted forms of external objective activity, which occur internally and in the new elements appearing in internal activity. Numerous studies conducted along the lines of microstructural analysis can be conceived of as a certain prototype, true not yet refined enough, of the planning of different functions of operator activity.

At present, there are many models of processes of receiving and processing information, which are not infrequently called models of short-term visual and auditory memroy. This is related to a persistent misunderstanding, which consists of the fact that the methods of microstructural analysis presumably are applicable only to the study of short-term memory. In fact, however, although they did originally appear in studies of short-term memory, they then were used for the study of virtually all cognitive processes, and recently also began to be used to study executory ones.

Figure 17 illustrates the block diagram of potentially possible types of conversion of input information in the segment between the input of the visual system to the verbal response. Depending on the objectives of observation and action, existence of sensory standards, operative units of perception, hypotheses, sets and a number of other factors, the perceived information can be submitted to various transformation. In other words, input information processing can be interrupted in any unit, and the units themselves may be involved in processing, in a different assortment and coordination. All these may serve as one of the grounds for interpreting the diverse individual distinctions that characterize human perception, memory and thinking.

Sensory memory: This unit is also called "sensory register," "very short visual memory," etc. The function of this unit consists of reflecting and engraving [in memory] of the object with all of its features that are accessible to the perceiving system, i.e., within the range of its resolution capacity. Information is stored in sensory memory for a short time, since it has to be free for reception of a new batch of information when the visual system is operating in a dynamic mode (constant change in fixation points), and the time thereof is of the order of 100 ms.

The spatial localization of objects is recorded in sensory memory. If it changes, information for analysis is delivered to higher levels of processing. Data about the volume and storage time for information in sensory memory are based on experiments, in which subjects solved the problem of identifying two successively presented arrays, consisting of randomly arranged black and white cells. An array [matrix] containing 64 cells was presented for 1 s, and after a variable interval it was followed by a second one exposed until the subject responded. The second array was either identical to the first or different in that it contained one black cell more or less. The answers were rapid and accurate when the interval between arrays did not exceed 100 ms. There was substantial decrease in accuracy of responses when the interval was longer [72].

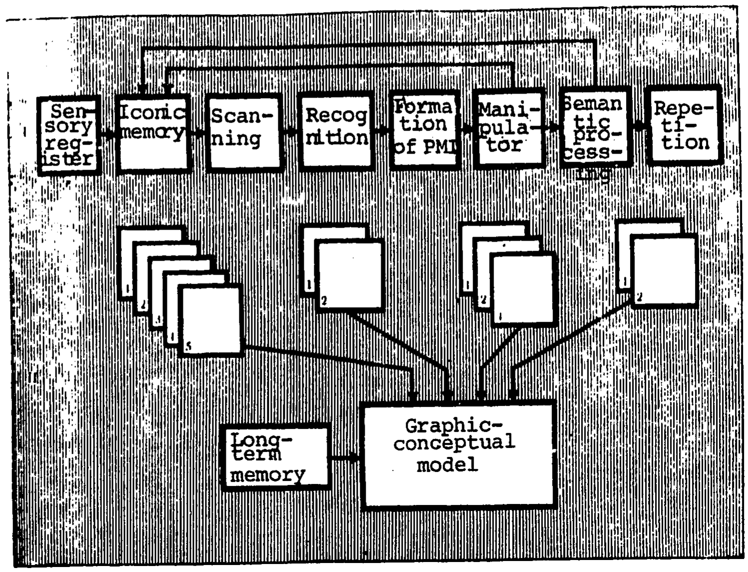

Figure 17. Functional block diagram of conversion of input information in short-term memory. Information is inputted in the graphic-conceptual model from different functional units of short-term memory (shown by Arabic numerals) and long-term memory

a) conversions that are possible during one visual fixation ["a" and "b" not shown in figure]
b) formation of immediate [operational] graphic-conceptual model of situation by means of information retrieval steps (I-IV)
PMI) program of motor instructions

We must call attention to the fact that the identification procedure, which takes place on the level of the sensory register, appears to occur on its own and does not require deliberate remembering of the control image, or detailed comparison thereof to the test image. The use of the mechanism at the basis of the sensory register permits substantial increase in labor productivity of specialists engaged in identification of different patterns (x-rays, aerial photographs, microcircuits, etc.).

Because of its enormous capacity, sensory memory serves the function of preafferentation and monitoring of changes occurring in the environment. Changes recorded in sensory memory are the cause for including other levels of information processing, which are responsible for detection, retrieval, recognition, as well as other forms of processing arrays of "raw" sensory information.

Iconic memory: While sensory memory stores all presented information, regardless of whether it is organized or not, in iconic memory there is conversion and storage of objective information in the form of sensory and perceptual standards, which can subsequently be categorized perceptually or verbally. The volume of information stored in iconic memory is very large, and overtly larger than the volume that can be reproduced or used to regulate behavior and activity. This surplus implies the selectivity of subsequent stages of perception and memory. According to existing estimates, up to 12 symbols are stored in iconic memory in 800-1000 ms [76]. Relatively longer storage of information in iconic memory is functionally important. Its first function is to preserve the visual "original," by means of which it is possible to monitor adequacy of transformations made in other functional units. The second function is that lengthy storage provides for an association between previously fixed traces and subsequent ones. Special studies [16, 33] demonstrated that 2-3 fixed traces (within 1 s) are accessible to analysis. Thus, there are both dynamic (conversions) and conservative (retention) components in iconic memory.

Scanning: Information stored in iconic memory is submitted to further processing. Here, a scanning mechanism plays an important role. Scanning the content of iconic memory takes place at a constant rate of 10 ms per symbol. According to experimental data, an observer can search for specified symbol in a changing information field at the rate of 120 symbols per second [27, 77]. It should be noted, however, that this mode of perception is a distinctive variant of blindness to the world, when man perceives only what he expects. The scanning mechanism is an effective means of overcoming superfluous and excessive information fixed in iconic memory. It experiences the influence of higher levels of information processing, which give it the retrieval standards and direction of scanning. There is discussion in the literature of a hypothesis that replaces the scanning mechanism with a filtering mechanism. In this case, the retrieval standards must shift to the level of sensory memory.

Buffer memory of recognition: The name of this unit indicates that it is the place of encounter of information from the outside world and from long-term memory. The recognition unit is a certain part of the contents of long-term memory brought to the input in the form of perceptual hypotheses, standards, operative units of perception and memory. The number of such hypotheses may vary. If it is small, the operative units of perception can shift even to the levels of iconic and sensory memory, being submitted to reverse transformation into the language of these units. It is quite difficult to estimate the number of hypotheses stored in the recognition unit. The number of surnames that are being sought in a text by professionals, according to the address classification of information, may exceed 100. For alphabetic information it does not exceed 10-12. If there are more letters to be searched, the reaction time begins to increase. For pictorial information, the number of perceptual hypotheses is apparently enormous, but it has not been precisely determined whether they are stored in the recognition buffer or long-term memory. It is important that the pictorial perceptual standards are very accessible. In the recognition unit there is distinction of informative features as related to expounded perceptual hyptoheses and comparison of incoming information to the actualized standards, images.

Formation of programs of motor instructions: Information that has been evaluated as useful must be changed in the recognition unit to a form that is suitable for its use. As we have already mentioned, it may be assimilated by the system of sensory or perceptual standards contained in the recognition [identification?] unit. Then the incoming information must be translated or related to certain motor programs. This is necessary for it to be possible to exteriorize the information, either in the form of verbal reports, or in the form of some other response actions. In this case, we should not be dealing with traces, standards or even images, but with efferent readiness, operative units of perception, sensorimotor schemes, efferent copies, programs of examination or execution.

It must be stated that studies of short-term memory have not yet offered strong arguments for separating the recognition unit and unit of formation of motor instruction programs. Some authors related transformation of information delivered by the scanning mechanism to the motor instruction program to functions of buffer recognition memory. The function of the repetition unit actually consists of running one of the possible programs that are formed in the recognition unit. The rate of the scanning block and recognition block, including formation of programs of motor instructions, is estimated at the same figure, 10-15 ms per symbol, but it is not indicated whether the operating time of the recognition unit is additional or whether it coincides with the operation of the scanning unit. In any case, it is important to note that the recognition unit operating time is longer by more than a factor of 10 than the operating time of the repetition unit (15 ms to form a program of motor instructions in the recognition unit and 300-500 ms to run this program). The maximum speed of repetition unit operation is estimated at 6 letters/second, although in memory experiments a rate of about 3 letters/second is more common. Evidently, the estimates of time of formation of programs of motor instructions are exceedingly exaggerated. We could agree with such estimates if we concede the possibility of existence of two types of motor instruction programs: potential and real. The former programs could be created at a rate that is close to the one assumed by G. Sperling, i.e., 10-15 ms/symbol. Real programs must have considerably greater details and, accordingly, the rate of their formation must be substantially lower. If we were to digress from real programs of motor instructions and accept the estimates of time of creation of potential programs of motor instructions, the question arises as to why such a reserve of stability is needed in the function of the first units, as compared to the repetition unit. It may be assumed that there are situations that justify the enormous speed of operation of units that are close to the input of the visual system.

Evidently, such situations are closer to real conditions of man's activity, when it is not so much complete reproduction of presented material that is required of them as recognition of the material, evaluation of degree of usefulness and selection of a small part of information that is relevant to the objectives of activity. It is logical to believe that, in such situations, it is not just any recognition that leads to formation of real programs of motor instructions for repetition (or execution) units. This is particularly apparent when we analyze information retrieval, in which there is something like "negative recognition," when the observer evaluates the information as useless and for this reason does not form a real program. As shown by numerous studies, the number of stored programs may be quite large, although their storage time is limited. As a rule, in situations of real activity, only part of the formed programs of motor instructions is realized. At the same time, it would hardly be correct to conclude that information that did not reach the repetition unit is lost and not used at all in behavior. The question arises: what positive function could these potential, superfluous and unrealized programs of motor instructions in the repetition unit perform? That these programs can indeed serve for certain positive functions can be seen from the so-called "rapid reading," in which a large part of the text bypasses the repetition unit.

Consequently, there may also be other units with two functions in the hierarchic system of conversion of input information, between the scanning and recognition units, on the one hand, and the repetition unit, on the other. In the first place, the speed of their operation should be commensurate to that of the recognition unit. In the second place, potential, still unverbalized programs of motor instructions must be the object of transformation. This brings us right up to productive functions of the described system of information processing.

Manipulator unit: We described above the characteristics of manipulative capacity of the visual system. In recent years, several studies were made of this capacity within the context of microstructural analysis of cognitive processes [8, 9, 16, 74]. Most demonstrative are experiments that were conducted by the method of determination of a missing element. In essence, this technique consists of the following. Before presenting a sequence of numbers in the same place in the field of vision, the subject is informed by means of digital instructions of the size of the alphabet (i.e., the size of the segment of the natural series of numbers, out of which a sequence will be chosen). After this, the subject is shown a series of digits, the length of which is shorter by one unit than the alphabet. The subject has to find the missing digit. The numbers were displayed for 50 ms with 50-ms intervals between stimuli. The results obtained indicate that the subjects succeed in solving the problem, even in the case of short intervals and series 9 digits in length. With such exposure time and interval, there is obviously not enough time to pronounce the presented numbers. Consequently, the subjects worked with nonverbalized potential programs of motor instructions. Formation of such programs in the described experimental situation was superfluous, since the subjects new in advance the alphabet of digits that would be presented to them. The task for the subjects was to "strike out" potential and superfluous programs. However, since the numbers were given in random order, this could not be done automatically as they were presented. These programs have to be stored and submitted to certain manipulations directed toward putting the random series in order. An important distinction of the manipulator unit is that information can be delivered to it successively and considered after the start of conversions that have already been made with the information contained in it. This provides for continuity of consideration of successively perceived information.

There are also data indicative of transformation of images of geometric forms, which occurs in the manipulator unit by means of operations (mental) of shift, turn and turning of images. The function of the manipulator unit is important to reinterpretation of visual stimulation, to anticipate the new position of an object in space and possible change in its form. Transformation of sensorimotor schemes, graphic images and more complex forms of cognitive representation, including symbolic, is possible in the manipulator unit. In other words, it makes a contribution to restructuring of the image of the situation, to putting it in a form that is suitable for decision making [33].

Unit for semantic processing of information: When discussing the possible transformations of information that take place on the route from forming a trace in iconoic memory to its reproduction, the question arises: is it possible for some operative units to be transformed into others: Can such transformations (like manipulations with motor instruction programs) take place before information reaches the repetition unit? To answer this question, a comparative experiment was conducted with two groups of subjects: an experimental group, consisting of experienced operator-programmers proficient in binary and octal calculation systems, and a control group consisting of subjects who were not familiar with these systems. The subjects were shown 19 binary digits for a short time (80 to 1000 ms). The display time was such that the obtained information could not be processed in the repetition unit. Nevertheless, the subjects skilled in recoding correctly reproduced all of the presented material in most cases. The same results were obtained with artist subjects, on whom a different method of perceptual grouping of information was used. They perceived zeros as the background, ones as figures, and this reduced significantly the number of objects to remember. These results serve as grounds to add another functional unit, namely the unit of semantic processing of unverbalized information.

The submitted results warrant the conclusion that, with a high enough degree of training, base information can go directly to the unit of interpretive processing, bypassing auditory memory. Only rather important information is transferred to the unit of repetition and, accordingly, auditory memory, rather than the initial sensory data. Overt or discrete pronunciation is the chief means of storing information in short-term memory and transferring it into long-term memory. Information can be stored for an unlimited time in long-term memory, apparently in the form of an abstract chart of logical statements, a sort of conceptual reservoir.

Such organization of correlations between visual and auditory short-term memory is all the more rational, since the visual system is indeed unique from the standpoint of instant grasp of a complex situation and capabilities of analog transformation of the primary reflection of reality.

The described system of information processing performs not only reproductive, but productive functions, including those that form meaning. The fact of the matter is that short-term memory does not function only as a device for receiving information, but it is the place of encounter of flows of information from the outside world and long-term memory. The individual always has his own system of previously formed operative units, which is involved in receipt of information and implements the second aspect of the comparison process, namely comparison of the object to the subject [individual].

The presence of productive units in the information processing system is indicative of the existence of one more form of comparison, i.e., comparison of information to the goals of solving practical and thinking problems.

To conclude the description of microstructures of initial levels of cognitive activity, we should briefly discuss the general distinctions of the described system of information processing. As indicated above, each of the units in these scheme first consisted of a certain theoretical construction, or model. Then the experimental conditions were created, under which a given unit could be demonstrated in the purest form, i.e., isolated from the influence of other units. Of course, this was not always successful. It can only be stated with confidence that, in experimental situations, the unit under study performed a dominant function. On the basis of the presently available results, the list of cognitive operations and units could be significantly expanded. There are also other variants of representation of the system of functional units, which are related to the theoretical and practical problems that are being solved by the researcher. The described system is intended for comprehension and details of processes of formation of a graphic-conceptual model under the natural conditions of operator activity, i.e., it is intended for description and interpretation of a living process of receipt and processing of information, rather than only its artificial laboratory analogs.

Several important conclusions ensue from these theses. The system of information receipt and processing is polystructured and heterarchic. In the course of its function, there may be involvement of different combinations, rather than all units. The general rule is that the units do not have their own, strictly fixed place and, consequently, the time characteristics of their function may vary. Regardless of the number of units that constitute a real process, the system is an organized entity, i.e., it is characterized by a specific arrangement of its elements and specific types of coordination of their interactions. Organization of the information processing system is highly dynamic, and its dynamics are determined both by the movement of information and relations to the environment. In the described system, the productive units are the least fixed: manipulator unit and semantic processing unit. In a number of situations they "shift" virtually to the input of the visual system, when retrieval of the meaning of a situation appears to precede its perception. At present, hypotheses are being expounded and finding some confirmation concerning the existence of precategorial selection, quasisemantic transformations that are made on the levels of iconic memory and even sensory register.

At present, investigators of short-term memory are looking for new conceptual schemes to describe it. Unit models of memory are being replaced with multidimensional spatial models. Experimental and theoretical research is overcoming the popular chronological and hierarchic models, and raising the question of designing models that adequately describe the effects of simultaneous processing of sensory and semantic information. Explanation of such effects requires reference to psychological and psycholinguistic studies of values and meaning on the figurative and verbal levels [51, 67]. Such studies are indicative of the similarity (and even identity) of semantic structures of figurative and verbal representation of phenomena on levels of deep semantics. In other words, gradually the rift between sensory and perceptual standards, mnemic schemes, nonverbalized programs of motor instructions and significance is being overcome, i.e., that which appeared to be a lower, presemantic level may very well be next to the conscious level of verbal information processing or even superior to it in a number of parameters and, first of all, productivity. Ergonomics and engineering psychology cannot fail to pay attention to these studies of cognitive activity, since optimization of figurative, sign-related and symbolic conception of information on display devices constitutes a substantial reserve for improving the efficiency of operator performance in man-machine systems.

Thus, microstructural analysis of cognitive processes is departing more and more from the initial simplified conceptions inherent in the informational-cybernetic approach. Considerably more attention is being given to psychological features of operations and functional units; the postulate of simple sequence of performance of elementary operations has been overcome. The data from microstructural analysis are being used well for interpretation of processes of preparation of information and decision making. Of course, it would be naive to assume that complex thinking activity could be made up of functional units. At the same time, the existing results of microstructural analysis are indicative of the inadequacy of many conceptions of thinking, which appeared without consideration of the real complexity of transformations, including semantic ones, that occur on the levels of perception, memory, perceptual-motor schemes, etc.

4. Preparation of Information for Decision Making

The urgency of studying processes of preparing information and decision making is related to the most important distinctions of man-machine systems (MMS). These systems must be able to solve creative problems that occur in the course of practical behavior. The practical behavior of the system or its function occurs under conditions of a large number of dynamic and interrelated factors, which together create much vagueness in the choice of optimum action. As a rule, an MMS operates on a real time scale, and always with a shortage of time. Finally, the MMS functions under conditions of a changing external situation and presence of competing, conflicting factors (which renders it, in essence, a game system). For this reason, it must be capable of taking into consideration the changes occurring in the external situation, determining the laws of occurrence of these changes in order to foresee them and adjust to them in advance or to counter them. An MMS, considered as a complex organism, must develop a model of these conditions or, in other words, a model of the external situation and of its own state. Since the external situation and the system's state change all the time, the system must continuously construct, alter and refine the models it creates. But, since it is possible to construct virtually an infinite number of models of the same situation, the control system must construct models that are consistent with the problems confronting it at a given time, i.e., it must convert the information to a form that is convenient for decision making and performance of executory actions. The decision that is made must take into consideration the state of variable and conflicting factors; a plan of behavior must be prepared for the immediate and more distant point in time. Decision making in the presence of uncertainty and conflict, which arise in MMS operation, is the prerogative of the human operator. Operators who make decisions in these situations are operator-investigators and operator-administrators, who work in the mode of operational thinking. The result of operational thinking or decision making in the MMS is the construction of the image of a new situation and of sequence of actions with controlled objects, by means of which the existing situation can be changed to the desired (including that dictated by the conditions) state. Operational thinking is closely related to practical thinking, the typical features of which were singled out by

B. M. Teplov [57]: the decision must be positive and the best under specific prevailing conditions (negative results are also theoretically valuable); the decision must be specific (on the basis of analysis of complex material, with mandatory distinction of what is important, one has to synthesize a decision that provides simple and definite theses); the decision must be strictly limited as to time.

In descriptions of operative thinking and decision making, much attention is given to intuition, i.e., the ability to rapidly discern a complex situation and almost instantaneously find the right decision. Intuition, or insight, is referable to the final stage of the thinking process, to appearance of the idea of the decision. The preceding stages are given much less attention, and this is reflected in the paucity of psychological interpretations of intuition phenomena. In spite of this, we can mention some of the features of intuitive decision and, although they were obtained by self-observation, they are apparently objective in nature, since there has been repeated and independent mention of them. These signs are: sense of complete confidence in accuracy of the result and clarity of what has to be done next [66, p 127]; sense of order, of the "required form" of the result, which is sometimes not reached immediately, but having been reached generates a feeling of confidence [65, p 150]; automation of actions after insight, performance of technical operations without reflection, with complete confidence that the desired result will be obtained [65, p 193].

Such features also characterize the result-producing part of operational thinking. However, the interesting feature of the final part of the decision making act can be defined only on the basis of comprehension of its preparatory stages, which have not been thoroughly studied by far.

Information preparation for a decision refers to the aggregate of actions and operations pertaining to receipt and processing of information about the external environment, state of the control system, progress of the controlled process, as well as ancillary and business [or service] information. In the course of these actions and operations, which include processes of information retrieval, detection, identification, recognition, recoding and transformation of information, presented on displays, the operator constructs a graphic-conceptual model (GCM) of the situation. If this stage of operator activity were to be compared to the numerous descriptions of the creative process, it is closest to the stage of inception of the topic.

This stage of activity is characterized by the fact that information is translated into the language of images, schemes, operative units of perception, i.e., which the operator knows. Subsequent processing of information is performed in this language, the language of the operator's GCM. At the second stage, the operator analyzes and compares the situation to the system of rating criteria and gages, which he has or which is specially developed for a given concrete case, which determine the nature and direction of changes in GCM of the situation. In descriptions of the creative process, this stage corresponds to the stage of perception of the topic, analysis of the situation and recognition of the problem. The main task at this stage is to transform the GCM into a model of the problem situation that arose in connection with the choice of topic. This new model, which is adequate for the objectively formed problem situation, is the area of crystallization of the problem that is to be solved. The first and second stages constitute conscious work directed toward creation of the GCM and model of the problem situation, its skeleton, scheme, i.e., self-styled functional organs of the individual.

While vagueness or an excessive number of degrees of freedom in the situation are fixed at the stage of formation of the GCM, at the stage of formation of the problem situation there is recognition (and interpretation) of the contradiction or conflict generating this uncertainty. As a result of this work, it often becomes possible to visualize the mental "landscape," in which events must take place and intuitive conception of their course.

At the third stage, there is intensive work to solve the problem. It consists of operating with base and transformed data, and it takes place in the form of purposeful actions, or else in the form of unconscious and automated operations, that are not always by far verbal. On the basis of studies of operator activity with graphic information models, it can be concluded that, at this stage, visual-spatial transformations and manipulations with elements of the problem situation or situation as a whole are the main factor. Attention is devoted chiefly to determination of different correlations between elements or complexes thereof that became contradictory and generated a conflict situation. In the course of such activity, a fuller idea is gained about the objective content of the situation, possible directions of its development, with structuring of the significance of contradictory elements, complexes and properties of the situation. The result of this work may be generation of new images, creation of new visual forms carrying a certain meaning and rendering the significance structured and visible. This type of activity is most often called visual thinking [64, 74]. At this stage, preparation of information for a decision changes into the decision making process.

The fourth stage is decision making proper. It is most often described as an instantaneous act of illumination, although it is preceded by lengthy work. Its main aspect is described in terms of occurrence of an idea, seeing the meaning and nature of previously detected contradiction or conflict. Nevertheless, the nature of "illumination" is still unclear, and it has yet to be investigated. Finally, the last stage--implementation of the decision--is the stage of executory actions, and it does not require any special explanations.

Processes of preparing decision making information are not unbiased. They are subject to the influence of so-called subjective factors, personal meaning, which include motives, subjective goals, sets, volition, etc. These influences affect the means of interpretation and transformation of conditions, and objective content of problems, accuracy of result obtained and the style in which it is implemented. Personal meaning elements affect processes of information preparation and decision making much more than the simpler executory and cognitive actions. This is attributable to the fact that rating criteria in complex situations, also characterized by a shortage of information about the environment, are usually evolved by the subject of activity. And this process of developing, putting them in one order and then in another, reorganization, is continuous in the course of thinking activity. Expressly it leads to a change in goals, development and formulation of new goals.

The significance of the role of unconscious elements in information preparing processes and decision making proper, as in any creative field, raises the problem of objective study thereof. Of course, the self-observation method cannot furnish accurate enough data, although very much can be extracted with it. This is also confirmed by the above description, in which we summarized chiefly self-observation data.

In both psychological and applied engineering psychological research, various experimental methods are sought and tested for analysis of thinking activity and its stages, phases, components. This search has not yet ended. The object of this research is so complex, that to study it one must use the most diverse methods, including those that would help differentiate between the isolated stages. At the present time, more successful studies are being made of the stages related to preparation of information and implementation of decisions than the stage of actual decision making.

Efforts have failed to use the characteristics of oculomotor behavior to predict time spent by an operator working in the mode of preparing information for a decision. With this form of work, there is impairment of regularity of saccadic movements (which is present in information retrieval problems [4]), and the time of visual fixation fluctuates over a very wide range, from 200 ms to many seconds. The reason for this is that other actions begin to participate in this form of activity, and there is also a change in composition of operations. For this reason, before formulating metric problems, one must demonstrate the composition of actions involved in decision-related preparation of information and, in particular, formation of the GCM and model of a problem situation.

Analysis of the microstructure of transformations of information led to the belief that information can be delivered to the GCM from different functional units, both in terms of primary reflection of reality and in terms of secondary or Nth reflection (figure 17). The same situation can be successively (or simultaneously) reflected by various operative units of perception and memory in the GCM. In other words, the GCM is a multidimensional reflection of reality, a reflection that is described in different perceptual, symbolic and verbal languages.* Accordingly, interpreted information extracted from the situation, rather than visually given base information, may be transferred into the functional unit for verbal recoding.

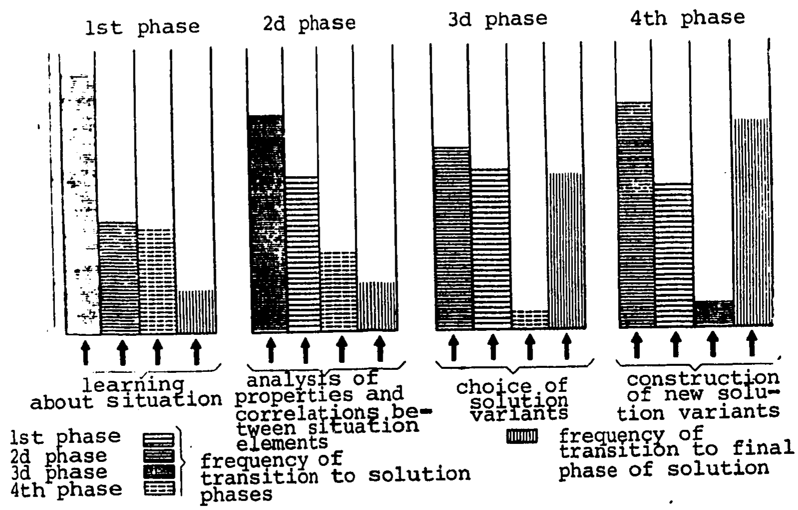

Figure 18. Frequency of transition between different phases of problem solving (% of total number of transfers; unlined section--frequency of transfers to decision phases; lined sections--frequency of transfers to final stage of decision making

On the basis of microstructural analysis of various conversions of information in the visual and auditory systems, one could conclude that perceptual, cognitive and mnemic actions are involved, not only in information preparation of a thinking act, but in making a substantial contribution to implementation of the latter. In the course of solving problems, a rather broad range of changes in information can occur, from scanning to nonverbal semantic transformations, at one step of information retrieval

*At the same time, in our opinion, the hypotheses of several psycholinguists of existence of deep semantic structures that are invariant in relation to all these languages [67] are highly plausible.

(i.e., in the time that equals the duration of one visual fixation). Depending on the difficulty of the problem solved, the number and type of transformation change, and this is manifested, in particular, by duration of visual fixation. This means that a man solving the problem has the ability to adjust ["tune in"] to the perceptual or semantic complexity of the information field. This capacity is similar, to some extent, to adjustment of the visual system to intensity of light flux. While the latter is manifested by pupillary reactions, adjustment for complexity is manifested by the duration of visual fixations and amount of information processed.

This is confirmed by studies of the rate of information processing in the case of data list coding. Alphanumeric lists were displayed to subjects in the same place in the field of vision. The problems changed from series to series. In the test, determination was made of the interstimulus interval between presentations of the lists, with which the subjects gave at least 90% correct answers. A rather wide range of change in rate of information processing was found, with the same amount and mode of presentation thereof, as well as in different problems solved by the operator. This rate varies from 1 to 100 symbols per second. Maximum speed was obtained in problems involving detection of a particular symbol using a well-learned system of coding information. The minimum speed was obtained when the means of semantic information processing required of the operators were excessively complicated [27].

As a rule, during actual operator work, the rate of information processing is not constant. This is related to the fact that the operator changes from the retrieval mode to the mode of construction of the GCM and solution mode proper. As we have indicated above, operator work takes place in stages, or phases. Phasic cognitive activity was demonstrated in studies of processes of solving operational problem on a power system mnemonics simulator. In this case (unlike information retrieval problems), the operators did not have any concrete or distinct identifying standards and rating criteria, and they had to form them in the actual solving process, basing themselves by the previously learned system of rules. In this study [40], there was polyeffector recording of several functional systems involved in preparation of information and decision making: EOG, EMG of the lower lip and EEG of the occipital part of the brain.

The operators were asked to analyze the state of individual power units or the system as a whole. Upon detection of deviations from normal, the subject had to make a decision as to the means of restoring the normal state. Parallel recordings were made of functional parameters of several physiological systems. It was found that, according to the electrooculographic data, one could distinguish four phases of oculomotor behavior differing in amplitude of saccades and duration of fixations. In the first phase, there were high amplitude saccades and in the second, low amplitude. In the first two phases, the fixation time was relatively short, in the range of 0.3-1.0 s. Then comes the third phase of long fixations (up to 5 s), alternating with high-amplitude saccades, and, finally, the fourth phase characterized by absence of macromovements of the eyes. This last phase could last tens of seconds. Depression of α-rhythm was the least marked in the first and third phases (to 40% of the background). Maximum depression of α-rhythm was observed in the fourth phase of the problem-solving process (80% of background). According to findings on electromyograms of the lower lip, the articulation system was involved at the final stages of problem solving. When solving the most complex problems, alternate involvement of all three recorded systems was observed; however, in this case, the share of the articulation system in the solving process remained small. The data obtained from studies of problem solving of this type do not offer grounds for singling out a special phase of operating with a verbal reflection of the problem situation.

Psychologically, the demonstrated phases could be interpreted as follows. At the first two phases mentioned, the subject becomes acquainted with elements of the situation and analyzes the properties and relations of elements. In other words, these phases are responsible for creation of the GCM and model of the problem situation. When solving relatively simple problems, one observes a transfer to the third phase, which can be interpreted as the phase of recognition of the situation, which is directed toward forming and assessing the suitability of the program of actions. The latter is constructed on the basis of several rules and modes of activity assimilated in the course of training. At this phase, a choice of variant is made out of a series of standard solution variants. Finally, in the more difficult cases, when the fourth phase is recorded, we are dealing with internal activity in the proper sense of the word. This activity is related to construction of an utterly new variant of solution on the basis of manipulation and transformation of the GCM.

Analysis of the correlations between the above-described four phases revealed that the process of solving complex problems is recursive in nature. There can be transfers from the first phase directly to the fourth, returns from the fourth to the first or second, etc. Transitions from the first to the third and fourth phases are the most probable. At the same time, there is maximum probability of transition from the third or fourth phase to the final stage, the stage of preparation of the solution in the context of internal speech and formation of an answer.

Thus, the recording of parameters of function of different physiological systems provides the grounds for objective evaluation of the functional structure of complex cognitive activity and characteristics of conversions that an operator makes in a problem situation.

Studies of the functional structure of microstructure of activity are necessary to optimize existing variants of information models. The information model should connect the operator to the control elements, rather than be a barrier separating him from them.

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CHAPTER V. ERGONOMIC BASES OF TECHNOLOGICAL DESIGN

Until recently, it was considered sufficient to solve problems of designing new equipment on the basis of considerations of its productivity, reliability and economy of operation. Now this view is being submitted to more definition and expansion.

The drastic increase in the role of the human factor in national production and real need for comprehensive development of man, due to the scientific and technological revolution, which are growing immeasurable in this period of developed socialism, compel us to take into consideration not only the economic, but social effectiveness of the new equipment designs that are being developed. "It is important here for the natural sciences to be fully aware of the studies, developments and conclusions of the social sciences pertaining to advancement of man's role in the man-machine system, the essence, forms and development of sociological, socio-psychological, ergonomic and ecological factors" [3, p 69].

In a fully developed socialist society, there is drastic increase in significance of qualitative characteristics of activity and labor; accordingly, increased demands have been made of refinement of consumer qualities of new technology [3]. More and more often, it is suggested that the traditionally used main parameters of technology (productivity, reliability and economy of operation) be augmented by indicators of ergonomicity, ecologicity and aesthetics, which provide for reaching social results related to safeguarding human health and development of the human personality, and on this basis for increasing the efficiency and quality of activity in the most varied areas. Social implications of new technology have become an important condition for realizing its potential economic effect. If, for example, optimum conditions are not provided for interaction between man and technology, one can hardly expect complete achievement of this effect.

"Socioeconomic effectiveness should become the main, if not only, criterion of formation of technological policy. For this purpose, already at the stage of scientific development and design of new technology, one must determine not only the economic effect of the newly developed technology, but the positive and negative effects that are potentially contained in technology, and consider their influence on the socioeconomic life of all members of society in plans for development of industry on all levels, from individual enterprises to the national economy as a whole" [2, p 25].

One can assure the social effectiveness of new technology provided the indices of ergonomicity, ecologicity and aesthetics will, along with the traditional indicators, define the general functional structure of the man-machine systems that are being developed. The social indicators of technology, including ergonomic ones, are a preset condition, for the implementation of which one selects the most economic variant that assures reaching a concrete, specified social goal with the least capital and operating expenses [4]. This does not refer to affirmation of the priority of man or machines in control systems, but to construct man-machine systems on the basis of knowledge about the objective [object-related] and structural patterns of man-machine interaction processes [15]. Only then will technology solve complex, i.e., dual purpose, problems, perform specific production engineering tasks and aid in creating optimum working conditions; and in any case it would prevent the adverse social consequences of using new technology in industry. "Endless appeals to the sense of social responsibility cannot protect modern man against the deleterious effects of technology; we need a real system of ways and means of controlling this under socialism. And the extent to which this struggle is conducted serves as an objective indicator of the progressiveness of the social regime, the extent to which its advantages are used" [18, p 78].

Use of ergonomic achievements in designing technology and its operating conditions aids in increasing the interest and attractiveness of labor, preservation of health and, ultimately, creation of conditions that are favorable to comprehensive development of working man. This provides for greater efficiency and quality of work, convenience in operation and upkeep of equipment, shorter period of learning to use it, better working conditions, saving of physical and mental energy of working man, and maintaining high efficiency.

1. Structure of Ergonomic Properties and Indices of Technology

Let us disclose the content of the concept of "ergonomicity of technology," which is a concrete manifestation of the activity-oriented approach in ergonomics. We submit here the structural diagram of ergonomic indicators of technological equipment. This is an hierarchic, dynamic structure consisting of several levels. Ergonomic properties and indices (essential features) of each preceding level are the basis for formation of the ergonomic indices of the next level. Here, the same general principle applies as the one governing interlevel relations between the structure of human activity, and which consists of the fact that the existing highest level is always the leading one, but it can express itself only by means of lower lying levels and depends on them in this respect [10].

The highest level of this hierarchic structure, ergonomicity of technological equipment--its integral characteristic--is organically related to the indices of productivity, reliability and economy of operation. Ergonomicity grows from a number of ergonomic properties, which include controllability, serviceability, assimilability and habitability. The first three describe the properties of equipment, with which it is organically included in the optimum psychophysiological structure of activity of a man (group of people) pertaining to control, servicing and assimilation of technology. Habitability refers to the ergonomic property of equipment, with which the conditions of its operation are close to optimal, from the standpoint of vital functions of working man (group), as well as provide reduction or elimination of deleterious consequences to the environment of equipment operation. The ergonomic properties of equipment constitute certain prerequisites, possibilities of human activity referable to its objective conditions.

Ergonomic properties are formed on the basis of complex ergonomic indicators, which represent various but interrelated aspects of these properties. Complex ergonomic indicators are formed on the basis of group ergonomic indices, which represent the aggregate of homogeneous isolated ergonomic indices: sociopsychological, psychological, physiological and psychophysiological, anthropometric and hygienic.

This structure permits representation of various levels of integration in ergonomics, each of which has certain qualitative specifics that cannot be reduced to automatic [mechanical] combination of its component indices. It is important for the designer to know not only the nomenclature and characteristics of ergonomic indices, but how ergonomic properties of designed objects are formed on their basis. In this aspect, design problems are the closest to ergonomics, the inception of which as a scientific discipline was largely determined by solving the problem of disclosing the patterns of transitions of some of the indicator levels discussed and equipment properties into others. Each step on the road toward solving this extremely complex problem again sets off the limitation and temporary nature of what is called consideration of the human factor, and it creates realistic conditions for developing a scientifically substantiated tool for purposeful formation of ergonomic properties of equipment in the designing process. In other words, there is substantial change in the role and place of ergonomics in technological design: from solving specific special problems related to partial improvement of man's work in already designed, specified technological systems, it moves toward full participation in the design of the general functional structure of man-machine systems.

We refer to the fact that, from the very start, the man-machine system is designed, rather than only the equipment which, only at the stage of practical "adjustment" to man, become elements of this system. The origin of the concept of "consideration of the human factor" in developing systems is related, not without grounds, to the fact that systems analysis considers man as an external factor and the technological part as the main component of the system.

The methodological significance of the proposed structure of properties and indices is that it opens up the way for truly comprehensive ergonomic description of man-machine systems which, in turn, permits the construction of models reflecting the corresponding patterns of their function. The theoretical bases of this structure have much in common with the theses of the systems analytical approach that is being developed for the study of the main element in the man-machine system, i.e., man, and the system as a whole [11]. This structure is an effective tool of ergonomics, by means of which appropriate study of man-machine systems is possible on a functional level.

The structure of ergonomic properties and indices of technological equipment stimulates the process of revision of some established conceptions of methods of planning it, which has already begun, and thereby is instrumental in its passage to a new, higher level. "Even now, it is apparently time to think of another direction, development of a technological assignment proceeding from ideas of the secondary, servicing function of machines and, consequently, with consideration primarily of the positive qualities of man as the real subject of labor, i.e., that which constitutes his advantages over a machine, rather than his shortcomings. On this road we find basically new reserves for increasing labor productivity, i.e., solving one of the most important problems under the current five-year plan" [17, p 63].

With reference to designing as a process that initiates changes in an artificial environment (see [6]), attention is focused on a task that was named "design forecasting" [13], which is a specific form of scientific programming of social and other consequences of design work. The large number and complex nature of such consequences, the fact that they are significantly deferred from the start and progress of the designing process proper--all this requires not only the use of new methodology, but participation of a large number of highly skilled specialists in collective preparation of designs. In design,forecasting the "static" object of design is replaced by a "self-developing" object, and for this reason there is a possibility of choice of optimum variants and sifting out of wrong versions in the course of designing, even before their adverse consequences could become and irreversible factor in reality. Scientific research, both applied and basic, turns out not to be merely an ancillary element, but an internal necessity that evolves organically from the very nature of designing work.

The above studies include investigation of the patterns of optimum interaction between man and machines. One of the central problems of ergonomics as a scientific discipline is to study the interlevel transitions in the hierarchic structure of ergonomic properties and indices, and first of all to demonstrate the patterns of formation of ergonomic properties of equipment, namely: controllability, serviceability, assimilability and habitability. "The main thing is that one cannot overlook the circumstance that, in interlevel studies, we are not dealing with unilateral movement, but with bilateral and helical at that: with formation of higher levels and "separation into layers"--or alteration--of lower levels that, in turn, determine the possibility of further development of the system as a whole. Thus, interlevel studies, while remaining interdisciplinary, at the same time preclude interpretation of the latter as reduction of one level to another or the desire to find their correlations and coordination" [10, p 233].

The problem of designing the activity of man (group) for the control (use) of technology is becoming an organic part of the general process of design. This problem can be solved satisfactorily if one is governed by ergonomics and other disciplines that deal with man and his activities. Such enrichment and complication of designing is consistent with the substance of technology which is "human" in its purpose and the progress of which occurs in accordance with the laws of development of human labor [12, 16]. K. Marx repeatedly stressed that technology refers to "organs of the human brain created by human hands" [1, p 215].

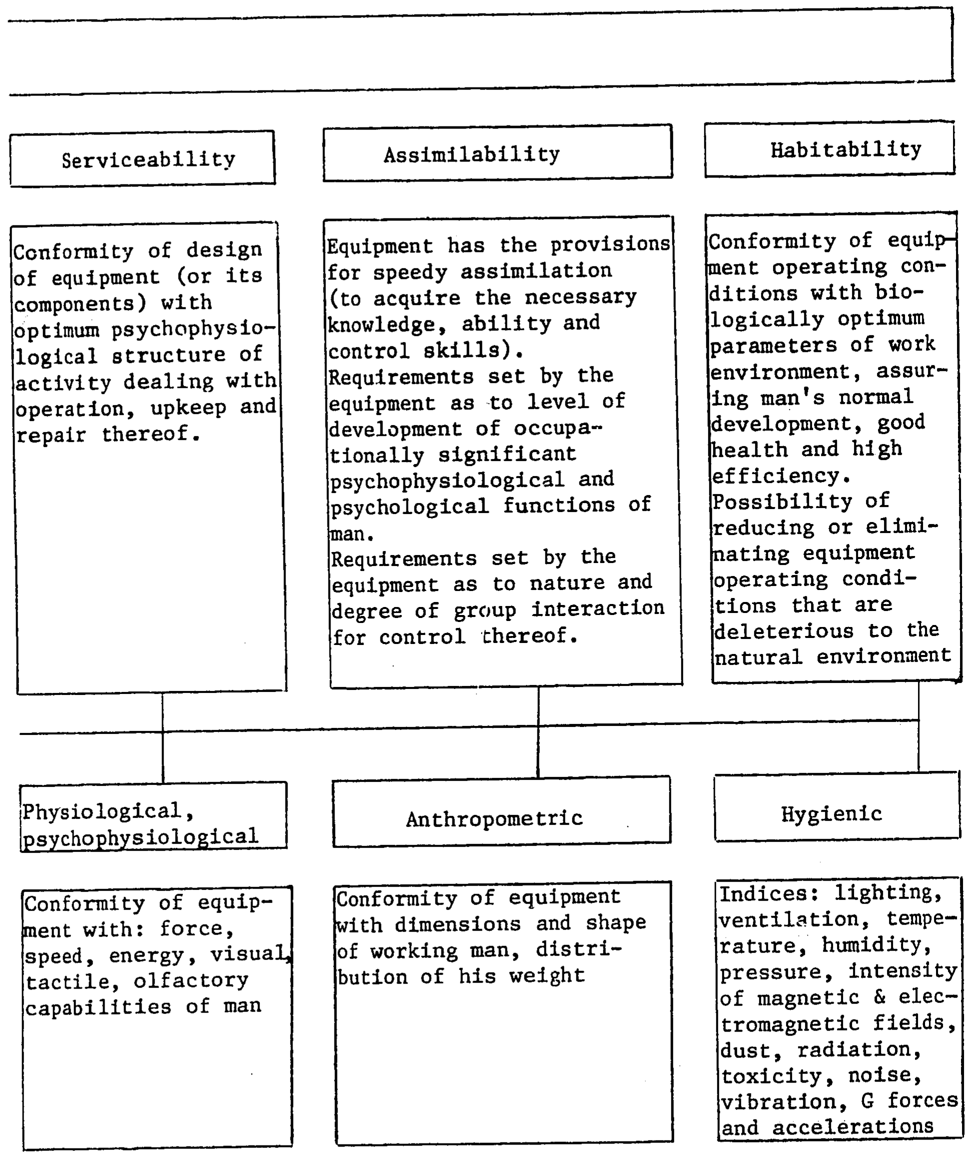
The real process of interaction between man and machine cannot be accommodated within the framework of general recommendations and concrete requirements of ergonomics. Basing oneself on these data, in the course of designing equipment one must solve the problem of comprehensive modeling of human activity and conditions under which it is performed. In other words, it is imperative to have a clear enough and comprehensive idea about what and how man will do with a given form of equipment and under what conditions. Development and evaluation on this basis of proposed designs to create convenient and safe equipment are distinguished in a special area of ergonomic design of man-machine systems. Being characterized by certain specifics, ergonomic design is governed by the general patterns and methods of designing work.

2. Consideration of Ergonomic Requirements in Equipment Design

With the existing practices and methods, equipment design, at best, only takes into consideration the ergonomic requirements at different stages of development, which permits achievement of some optimization of activity of a man (or group) in the man (group)-machine system and, accordingly, increasing efficiency of system operation as a whole. Ergonomic requirements of equipment are determined by psychological, anthropometric and biomechanical features of man, and they are set in order to optimize his performance. Ergonomic requirements refer to features which, being embodied in equipment, become its properties and indices [5].

Integral ergonomic feature	Ergonomicity of technology	
Ergonomic properties	Controllability	
Complex indices	Conformity of distribution of functions between man (group of people) and equipment with optimum structure of their interaction in reaching set goals. Conformity of design of equipment (or different elements thereof) and organization of work place with optimum psycho-physiological structure of activity to control it. Conformity of content of control activity set by equipment with optimum level of complexity and diversity of man's actions. Conformity of intensity of activity set by equipment with minimal strain, with which maximum efficiency of control is reached. Conformity of requirements made by equipment of quality of control activity with optimum accuracy, speed and reliability capabilities of man. Conformity of equipment-set rhythms of work processes with optimum time structure of actions of working people.	
Group indices	Sociopsychological	Psychological
Isolated indices	Conformity of design of equipment and organization of work places with nature and degree of group interaction. Degree of mediation of interpersonal relations by the content of joint activity to control technological equipment.	Conformity of equipment with: capabilities and distinctions of perception, memory, thinking, psychomotor activity, fixed and newly formed skills of working man.

Structural diagram of ergonomic properties and indices of equipment
[chart extends to following page]



Structural diagram (continued)

Ergonomic design and research problems are solved in relation to concrete types of man-machine-environment systems, specific types of man's activity.

Consideration of ergonomic requirements must permeate all stages of preparing designs and expert evaluation thereof. At the stage of development of a technological assignment in general form, determination must be made of the ergonomic requirements of the object of design and of the need to conduct special ergonomic studies. It is very important to correctly translate the problem from the language of engineering design to the language of ergonomics by means of analysis of this problem in the context of the specific problems of the human factor. For this, analysis is made of the purpose of the object to be designed and related operating requirements; determination is made of the place and role of man in solving problems ensuing from the above-mentioned purpose.

The specialist in ergonomics, who becomes part of a team of designers and participates in the process of equipment design, is dealing with a special object of design, man and his activity, the means of which are knowledge about man and relevant special methods and procedures [8].

Man's activity in the system is the beginning and end of ergonomic design, evaluation and study. Already at the first stage of design, a tentative professiogram is plotted, which defines the goals and objectives of work, psychophysiological conditions, composition and content of operations it involves, as well as the concrete requirements made in a given instance of man and machines.

Professiography is a complex and precise art. Specialists who analyze work activity can be compared to a keen therapist, in whose practice scientific methods are combined with rich intuition and experience. Occasionally, the ergonomist himself masters the work activity, at least to an elementary degree, and thus is able to analyze it "from the inside." A professiogram is the starting point of ergonomic research and the foundation for all work dealing with consideration of relevant requirements in designing technological equipment.

Analysis of analogs and prototypes pinpoints knowledge about the purpose and principles of action, as well as structural features of a machine; it determines its characteristics as applied to the goals of work activity and its optimization, including creation of optimum conditions for operating, servicing and repairing the equipment designed.

Distribution of functions between man and machine is an important designing task. It cannot be performed solely on the basis of engineering approaches to distribution of functions in a man-machine system, especially since none has the necessary universality and effectiveness of applications [14].

The problem of choice of degree of automation and mechanization of functions is rather complex and important. For example, planning the work of a pilot during an automated landing made it possible to determine the desirability of semiautomatic, rather than automatic control on the approach path, since in this case the pilot's readiness to take over manual control in the event of sudden malfunction of automatic equipment is sustained at a high level thanks to retention of the status of his readiness for emergency action, in the first place, and retention of closer contact with the controlled object, in the second place [7]. It is very important not to disrupt some integrity of structure of man's activity when choosing the variant of rational distribution of functions.

When selecting a variant of distribution of functions (and different forms thereof), general methodological considerations must also be borne in mind, with respect to man's social function as the subject of labor, as well as the results of concrete ergonomic, psychological, physiological and other studies. It is also apparent that, at the present stage, substantiation of rational or even optimum distribution of functions must be based on quantitative estimates of the quality of man's (and machine) performance and evaluation of the influence of this quality on the overall efficiency of the system. Thus far, there has not been sufficient development of such criteria; however, by no means can this serve as justification for the disregard for quantitative evaluation methods that is still encountered.

There are some substantial flaws in the existing methods of qualitative evaluation based on lists of advantages and limitations of man and machines. These lists are too general, and they do not take into consideration of the specifics of man-machine interaction, limitations and factors of an economic and social nature, as well as questions of human motivation. Finally, they are far from strict coverage of existing (and quite insufficient) time and accuracy parameters of operations performed by man.

When trying to apply quantitative methods to substantiate distribution of functions, the main difficulties arise more because of the absence of data pertaining to some important parameters of the man-machine system at the early stages of designing, which is precisely the time when the problem of distribution of functions must be solved, than because of the lack of refinement of formal optimization procedures.

It is quite obvious that progress in solving the problem of distribution of functions can only be made along the lines of combining qualitative and quantitative evaluations, with prevalence of the latter. Such combination must, of course, be based on a clearcut classification of the problems to be solved and analysis of their components, primarily the concrete operations, the performance of which makes up the process of work pertaining to control of equipment.

After determination is made of the sequence of operator performance of functions (according to subproblems, operation units, main operations, etc.) and of the required scope and form of information display, as well as at least general determination of reliability, time and precision requirements of man's work as a whole, one can furnish substantiated answers to the following questions of developers of man-machine systems: How many people and what qualifications are required to solve problems of MMS and expressly what functions must they perform? What algorithms and computer programs must be developed? What equipment must be designed or taken from existing system? Then the following is determined: 1) final complement of specialists for the MMS, their functional duties and organization of work; 2) composition of collective and individual means of displaying information, control elemements at work places and control consoles; 3) arrangement of means of displaying information and controls at the work places, and arrangement of work places in industrial premises.

We submit an example of general procedure for choosing a variant of rational distribution of functions, which was developed in designing "Man (group) - ship engineering" systems, the basic theses of which are applicable to other man-machine systems as well [5, p 143] (Table 1).

High professional requirements are made of the analytical stage of an ergonomist's work, since his findings should constitute the solution of basic ergonomic problems of upgrading an existing piece of technological equipment or a new one being designed. At this stage, there is the most effective manifestation of collaboration between the ergonomist, designing engineer and designer, the mutual understanding of which usually enriches the conception of each of them of the general object of design, and permits finding the most productive designs, including those based on knowledge of psychophysiological patterns of human activity. Determination of the necessity and purpose of experimental ergonomic studies is made from the results of the analytical stage.

Ergonomic analysis of work activity and distribution of functions between man and machine create the necessary foundation to develop first general and then detailed algorithms of human work. The essence of development of algorithms consists of differentiation of work activity into qualitatively different components, definition of their logical interrelation and order of following one another [9]. Algorithmic description of work allows us to turn to definition of the psychological and physiological functions that implement separate elementary actions and logical conditions.

After performing the above actions, we turn to direct development of ergonomic requirements of equipment and its operating conditions, its separate elements and work places, which are then embodied in the design and organization of all of the items mentioned. The system of developed designs and expert evaluation thereof, which assure consideration of ergonomic requirements, is not a unidirectional process of successive movement from stage to stage; rather, it often includes movement in the opposite direction, with subsequent return to the initial position and further advancement forward.

Table 1. Procedure for selection of a variant of rational distribution of functions

Problem solving stages	Content of problem solving
Preliminary distribution of functions	1. Compilation of total list of all functions imposed on the designed man-machine system. 2. Determination of characteristics of each function by means of expertise methods. 3. Choice of functions that should be performed, in principle, by technological devices. 4. Ranking the remaining functions according to one or several features. 5. Distribution of functions between man and machines by means of one of the qualitative methods
Evaluation of adopted variant of distribution of functions	1. Development of general abgorithms and formulation of structure of man's activity referable to performance of all functions assigned to him. 2. Obtaining base data for quantitative evaluation of activity according to appropriate indices.
Redistribution of functions (in the event the obtained indices do not meet the requirements of the technological assignment) and determination of number of specialists in each man-machine system (individual or group work place)	1. Reduction (increase) in number of functions delegated to man and increase (reduction) of machine functions, and, consequently, of expenses to develop the equipment. 2. Creation of group work place if one cannot rationally distribute functions with one person. 3. Determination of number of specialists for each work place. 4. Determination of total individual work places in each MMS 5. Determination of mode of MMS function (continuous, periodic, episodic)

Development of an artistic design for a hydraulic copying lathe with programmed control can serve as an example of practical implementation of the above general scheme of ergonomic designing (in a somewhat reduced form). Although, in this case a new lathe was not developed, but an existing one updated, ergonomic designing was rather deep and multi-faceted.

The work started with becoming closely acquainted with the main principles and technological distinctions of operation of semiautomatic copying lathes, that distinguish them from general purpose lathes and semi-automatic ones of other types.

At the second stage, the tasks confronting the designer group in the ergonomic aspect were formulated and defined on the basis of the obtained data and preliminary professiogram of lathe operator work: spatial organization of work places for lathe operator and repairman [trouble-shooter]; rational lay-out of control elements and display means in order to reduce fatigue related to distinctions of professional activity; lowering the probability of erroneous use of control elements; reducing time required to service the lathe during work.

The place of the lathe operator, as the representative of the largest occupation in operating lathes, rather than the work place of the repairman, was chosen as the main place to be remodeled. This was also attributable to the fact that the work of a lathe operator is notable for high monotony, stereotypism and repetition of operations within a limited space. As we know, with monotonous activity attention declines and fatigue develops rapidly which, in turn, could lead to cases of industrial traumatism. For this reason, improvement of organization of the lathe operator's work place, reduction of static and dynamic muscle load, and improvement of organization of the sensorimotor field should aid in creating optimum conditions for work activity, longer maintenance of a high level of efficiency, economy of human resources, as well as more efficient operation of the lathe.

The third stage dealt with professiographic analysis of lathe operator work under industrial conditions, with both domestic and foreign lathes analogous to the one being updated. The main work operations were singled out; operation-by-operation time studies were made; determination was made of the frequency of using various controls and of the nature of monitoring the technological process.

The fourth stage consisted of ergonomic analysis of organization of the work places of the lathe operator and repairman on a prototype of the lathe in the adjustment and automatic modes. It is known that the spatial arrangement of lathe working elements largely determines the scope and nature of the operator's sensorimotor activity and, consequently, the efficiency of his labor. Hence, much attention was given to the study of the specifics of work operations taking place in the work zones of the lathe.

Analysis of each operation made it possible to rank the work operations according to their significance to the technological process, to determine the preferred work zones for each group of operations and relate them to existing designs of equipment. For a lathe operator, the main zone was found to be the one related to installation of work pieces [or parts]. There were more such zones for the repairman: in addition to the zone related to installation of pieces in common for both the worker and repairman, the latter can also work in the zone of the programming array [matrix] located in a separate cabinet, in the zone of the lathe's drum and fine manual adjustment of cutting tools; there are also several ancillary work zones, in which episodic, one-time operations are performed.

Graphic analysis of the layout design was made by means of superposition on orthogonal projections of the lathe prototype of the outline of maximum range of the sensorimotor field determined experimentally. From this, it was easy to see that all controls, display devices and work surfaces were within reach of a working man in two main working positions. The conditions were not optimal for demonstration of his work activity as a whole, because the work surfaces were not always correctly oriented. For ergonomic optimization of the general lay-out, it was also suggested that the depth of the lathe be reduced over its entire length.

The most appreciable flaw in organization of the work place was the spatial separation of zones of control and monitoring the object of labor and tool, i.e., the zones of motor and sensory activity of the worker, which leads to unnecessary expenditure of his muscular and mental energy. Such an excessive load is particularly inadmissible in the work of the repairman, since the quality of the entire series of articles subsequently produced on the lathe depends on accuracy and quality of adjustment. Some inconvenience also arose in performing fine manual adjustment with the use of graduated circles, upon turning of which the worker blocks the disks with graduations with his hand.

Several design flaws were demonstrated by analysis of ancillary operations. In particular, the ill-chosen location of the top master form requires much physical force to immobilize the pieces, unnecessary movement of the repairman during work; the ill-chosen design of protective shields leads to appearance of superfluous operations and prolongs the processing cycle.

Ergonomic analysis revealed flaws in the control console, on which a significant number of controls, displays and monitoring devices is concentrated. Expressly in the zone of the console the greatest part of the most important operations is performed as indicated, in particular, by the frequency, with which the repairman refers to this zone. When operating in the automatic mode, the console becomes the principal element of the work place, i.e., concentration of the worker's motor activity. As shown by analysis, a significant part of the console is below the optimum zone of sensorimotor activity of both the repairman and lathe operator, while there is no standard principle of grouping controls according to functions, sequence of actions, etc. From the standpoint of the repairman, the horizontal arrangement of controls and displays pertaining to work with the top copying support is inconvenient. The need to move controls to the far right to operate this support makes it preferable to arrange them vertically, rather than horizontally.

As a result of the analytical work done by ergonomists, there was an assignment given to designers, which amounted to the following main items in general form: improve conditions for coordination of sensory (mainly visual) and motor activity of lathe operator and repair man; improve conformity of spatial parameters of the lathe with anthropometric data for individuals working on it; have the programming matrix together with the control console; optimize arrangement of controls on the console in accordance with the distinctions of the work of the main group of specialists operating and servicing this lathe.

The concrete ergonomic recommendations consisted of the following: to try to reduce the depth of the lathe; install back-up controls on the back mandrel; move the device for presetting the support to the control console; raise the console so that all controls are in the optimum zone; tilt the console; group controls and monitoring devices according to function; arrange controls vertically instead of horizontally; additionally provide visual distinction of each functional group of controls (for example, by color); the working elements related to the top copying support should be placed in the right top corner of the control console at a height of 120-150 cm above the floor; controls for the bottom copying support should be arranged next to them or somewhat lower.

In addition, several special comments were made: provide for the possibility of installing pieces of any size without removing protective shields; revise the design of protective screen handles; provide local light for the lathe; provide a device to support the master form, especially when its length is significant, to alleviate the installing operation and thereby reduce the worker's physical tension.

A special stand was produced for experimental ergonomic studies, which permits dynamic reproduction of spatial conditions of lathe operator work. On this stand, several three-dimensional models of the lathe and work zone were reproduced successively by means of sliding rods and suspended equipment simulating the main working elements of the lathe (clamping chuck, rear mandrel, etc.). Bioelectric activity of muscles was recorded while subjects worked on the models. The obtained myograms made it possible to choose one out of several tested models, the dimensions and geometric shape of which involved minimal muscular tension for the lathe operator to maintain a work pose.

Table 2. Sample content of ergonomic work at the different stages of designing equipment

Stages	Main ergonomic tasks	Results of work
1. Engineering assignment	1.1. Determination of purpose of equipment, analysis of analogs & prototypes, and their erognomic description	Preliminary professiogram
	1.2. Ergonomic analysis of man's work in real MMS (or preparation of program for planning man's work in a newly developed system)	Preliminary ergonomic requirements of man, equipment, work place, industrial environment
	1.3. Tentative distribution of functions in man-machine system [MMS]	Assignment to conduct ergonomic research
	1.4. Tentative ergonomic requirements on the basis of existing standards, ergonomic reference material and results of items 1.1, 1.2 and 1.3	
2. Engineering proposal and design sketch	2.1. Definition of distribution of functions in MMS and preparation of general algorithms of man's work	Specification of ergonomic requirements and implementation thereof in engineering proposal and design sketch.
	2.2. Specification & implementation of proposals and draft of tentative ergonomic requirements of worker, equipment, work place, industrial environment.	
	2.3. Ergonomic evaluation of design variants	Results of expert's evaluation of design
	2.4. Studies in laboratory and under industrial conditions to define algorithms of work and ergonomic requirements	
	2.5. Preliminary evaluation of degree of implementation of ergonomic requirements by analytical and modeling methods	
3. Engineering design	3.1. Final distribution of functions in MMS and preparation of detailed algorithms of man's work.	Ergonomic requirements and their implementation in engineering plan.
	3.2. Determination of final ergonomic requirements & their implementation in plan.	
	3.3. Evaluation of degree of implementation of ergonomic requirements by analytical and modeling methods	Results of expert evaluation of designs

Table 2 (continued).

Stages	Main ergonomic tasks	Results
4. Preparation of drawings and testing	4.1. Analysis and experimental evaluation of designed product under real operating conditions to determine extent of satisfying ergonomic requirements 4.2. Proposals to refine (upgrade) product and corresponding amendment of design 4.3. Ergonomic characteristics (evaluation) of product quality 4.4. Preparation of ergonomic requirements pertaining to instructions on operation and upkeep	Ergonomic characteristics of equipment, work places, industrial environment; proposals to improve them; requirements referable to operation and upkeep of equipment

The final stage of the work was to compare two variants of the prototype lathe to the design of an updated lathe. Graphic-analytic methods and electromyography (recording biopotentials of muscles) were the main techniques used.

Graphic-analytic methods combined with photography were used mainly to analyze the characteristics of the work space zones, main working body positions and visual monitoring zones. Electromyography was used to analyze overall energy expended by the worker to perform the main operations with change in spatial organization of the motor zone (a comparison was made of data for the prototype and modified lathe variant). The studies were conducted on the above-mentioned stand, which permitted rapid reproduction of any spatial conditions of activity (for example, the parameters of the main work zones of the prototype and modified variant when performing the operation of placing an article, etc.). These methods were also used to determine optimum location of fine adjustment controls (levers with dials).

Analysis of the obtained data revealed that there was considerable decrease in muscular fatigue (particularly of muscles of the back and abdomen) and decreased asymmetry of function of the strongest muscles carrying the static load, which generally reduced energy expended by the body, when working on the modified variant of the lathe (both lathe operator and repairman). At the same time, there was faster and more accurate reading of display and monitoring instruments, and in the course of comparative analysis it was found possible to additionally refine the design of some units and parts of the lathe.

As a result of expert ergonomic evaluation of the two lathe variants, there was demonstration of the advantages of the developed artistic design, from the standpoint of providing optimum working conditions and increasing efficiency of lathe operation. Routine and adjustment work was alleviated by placing the panel with the set of programs and control console of the lathe in the same place, next to one another, on the same plane, in a zone convenient to the worker; replacement of manual setting of stops with instruments to measure cycles; back-up control console was placed on the rear mandrel; glassed off area of protective shields was enlarged and their weight reduced; notches were cut on the front and sides of the lathe to provide a normal foot position and posture of the worker; there were also other improvements that simplified servicing and upkeep of the lathe. Rational design of electrical and hydraulic systems of the lathe, a search for which was prompted also by the task of providing for convenient servicing and upkeep of the lathe, reduced its dimensions: the length by 250 mm and width by 253 mm, as a result of which the area it occupied decreased by 1.5 square meters. In addition, uniformity of composition and color of the lathe was provided. At the same time, it must be conceded that the fact that it was impossible to make radical changes in the construction and arrangement of this lathe limited substantially the opportunity to come close to optimum working conditions for the lathe operator and repairman.

Many ergonomic norms and requirements have been reflected in GOST's: Man-machine systems, Systems of standards for labor safety practices (SSBT), Sanitary norms and rules, Standards for terms and nomenclature of ergonomic indices of quality, as well as other standard-setting documents. Consideration of ergonomic requirements in designing technological equipment implies unfailing adherence to the standard-setting documents listed. Table 2 lists the exemplary content of work that must be done in full with regard to consideration of ergonomic requirements at all stages of development of complex technological equipment.

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CHAPTER VII. OPTIMIZATION OF INFORMATION DISPLAY SYSTEMS AND MEANS

1. Operator Work With Information Models

Development of industry in the 20th century is increasingly characterized by mechanization and automation of production processes. In a number of cases this results in the fact that it is not so easy to specifically indicate and define the object of labor and its results with respect to many types of activity. The fact of the matter is that the means of work are beginning to take the place of its object in the worker's consciousness, while the object itself is, so to speak, "dematerialized." This process of dematerialization occurred gradually. There were and are many situations when the required accuracy of direct observation and evaluation exceed the resolution capacity of human sense organs. Various sensors, information from which is submitted in analog or digital form, began to be used to increase the accuracy of direct observation. This information duplicates in part the direct perception of the object of labor or work process. Instrument information is displayed in the most convenient form for perception. The use of such dual sources of information is the start of "splitting" of the object of work. Man is beginning to deal not only and, in some cases, not so much with directly observed properties, as with instrument-measured properties of the work object. Such situations are typical of many transport-related occupations, metallurgists, tool makers [or workers], etc. As man removes himself more and more from the object of labor, by virtue of impossibility or hazard of direct observation, diverse means of remote monitoring and control, special information display devices, began to be increasingly used. The latter are intended to display to man the data characterizing objects of control or their parameters, progress of a technological process, presence of energy resources, state of automation equipment, communication channels, etc. These data are displayed to man in quantitative and qualitative, including pictorial, form.

As a result of introduction of systems of remote monitoring and control, information display equipment began to be used as the only source of information about the controlled object, work process, as well as the state of the remote control system or man-machine [MMS] system. The operators of such systems do not work with real objects, but with their substitutes or images that simulate them, i.e., with information models of real objects. The latter, being the means of operator work, not infrequently also become its object.

The information model is a set of information, organized in accordance with a certain system of rules, about the state and operation of the object of control and environment. It is a unique simulator for the operator, which reflects all of the properties of real object that are essential to control, i.e., the source of information, on the basis of which he forms an image of the real situation, analyzes and assesses the formed situation, plans control action, makes decisions that assure proper operation of the system and performance of tasks imposed on it, as well as observes and evaluates the results of this performance.

In the methodological philosophical literature, model refers to functional homomorphic transfer (reflection) of part of the outside world to a system of concepts (images, visualized pictures, symbols, signs, etc.). This reflection is not unequivocal, i.e., isomorphic; however, it retains the relations that exist between elements of the outside world. The latter property enables the model to be not only descriptive, but predictive. In accordance with this definition, the important components of the model are: 1) concepts (terms, signs, symbols); 2) postulates (axioms or laws); 3) rules of transformation (rules of calculation); 4) rules of conformity, reflection, which permit comparing the results of calculations to experimental or practical results. These four general theses can describe theory models, as well as very simple models. Working ["operational"] definitions of a model are also common. A system is a model if it is capable of answering questions about the outside world. An important advantage of a working definition is that it includes not only theory models, but cybernetic systems created with computers.

According to the generally recognized thesis that a model that is too abstract is useless, while one with too many details leads into error, the volume of information included in a model and rules of organizing it should conform with the objectives and methods of control. Physically, an information model is rendered by means of diverse devices for display of information.

The most essential distinction of man's work with an information model is the need to relate information obtained from instruments, screens, mnemonics, signal panels, etc., both to one another and to real controlled objects. The entire activity of an operator is based on procedures of relating such information. Hence, it is understandable that construction of an adequate information model is one of the most important tasks of designing a control system as a whole.

In work dealing with creation of information models, which precedes the choice of technical means of implementing it, i.e., information display means, one must be governed by the following ergonomic requirements: with regard to content, information models must adequately reflect objects of control, work processes, the environment and state of the control system itself; with respect to amount of information, information models must provide the optimum balance of information and should not lead to such undesirable situations as shortage or surplus of information; with respect to form and composition, information models must conform with the objectives of the work process and man's capabilities pertaining to receipt, analysis, evaluation of information and execution of controlling actions.

Comprehensive consideration of these requirements in the course of designing results in the required flexibility [dynamics] and accuracy of man's work and, in particular, efficient performance of functions by the MMS.

The information models of modern MMS's do, in most cases, adequately reflect objects of control and state of the control system. Nevertheless, the work of an operator with them often fails to meet the requirements of flexibility and precision.

Experience shows that operators often encounter difficulties, which are the result of the fact that the designer proceeds from the wrong or incomplete conceptions of human capacity for receiving and processing information. This is also related to miscalculations, such as a poor choice of coding system, display of excessively large volumes of information or too rapid succession thereof, not to mention disregard for elementary psychophysiological requirements. The main reason for this is that the information model is not infrequently based on the system of correlations of a real object, which does not take into consideration the specific distinctions of psychological structure of man's work with this object.

The objective [object-related] content of operator work is quite diverse. This diversity is reflected in the classification of automated control systems (ASU). One should only add to it the control system proper and its elements, which emerge as the special objective content of work of operators engaged in functional monitoring and servicing of automated equipment. The description of objective [object-related] content of objects of control must necessarily include time-space and dynamic parameters of their existence, operation and interaction.

Incidentally, in order to illustrate the diversity of objective content of operator work, it should be recalled that his own functional state also serves in this capacity. This is typical of the biomedical, psychological and ergonomic studies conducted by cosmonauts.

Analysis of objective content of work is the basic and mandatory condition for solving any ergonomic problems. The details of objective content of activity are particularly needed at the stages of development of information models and operator training.

A description of the psychological content of operator work was offered in the works of D. Yu. Panov and V. P. Zinchenko [8, 9], after which it was reproduced numerous times, with additional details and definition as related to various forms of operator work. Here, it should be stressed that ergonomics and engineering psychology study and plan expressly work with information (and executory) models. The term, "interaction of man with automation equipment," is not infrequently used in engineering psychology. However, this term does not permit fixing the specifics of human activity. As we know, automation devices can interact with one another even without the help of man. It would not have been necessary to discuss this if the terms, "information interaction," "information exchange," etc., did not set the wrong methodological orientation for studies in ergonomics and engineering psychology.

The concept of activity is also applicable when dealing with man-machine dialog. There is always a leading partner in any dialog. The only change in man-machine dialogs in automated control system is that the operator has considerably greater freedom of operation with an information model, as compared to first generation ASU. Evidently, in the future, operators themselves will determine, to a certain degree, the content and form of information model, addressing themselves to the information software of ASU's.

The key problem of psychological analysis of operator work is related to the content, form of permanent and operational graphic-conceptual models (GCM) of the real and predicted situation, the control system itself, potential and real problem situations. The GCM also contains a system of evaluations and values, operational capabilities, a general conception of time and space, and the specific mode of interaction between the individual and the outside world. The problem of internal models of the surroundings [environment] emerged earlier in philosophy and general psychology than in engineering psychology. These models were also called subjective, conceptual. (Incidentally, we could also mention the use of the terms, "cerebral" and "mental [psychic] model," which are the same in meaning but inadequate in form.)

Within the context of research in engineering psychology, the problem of internal and conceptual models was formulated in England in 1943; but after this it could not be properly elaborated for a long time. Interest in this problem was revived in the last few years, in connection with the arrival of cognitive psychology to replace neobehaviorism and the information approach. In our literature, there are many experimental psychological studies dealing with the problem of formation and function of GCM.

This is related to the main orientation of Soviet ergonomics and engineering psychology toward formation of a system of rational actions in an operator, rather than chains of reaction. Although requirements are made of man's work in an ASU with regard to speed, promptness, immediacy, this does not mean that man has to develop reactive, impulsive forms of behavior. To stress the significance of the GCM in operator work is to stress the rational, conscious nature of his activity.

The difficulty of rational definition (and planning) of operator work is that he is put in the control system to perform functions for which it is often impossible to elaborate clearcut and unequivocal instructions and rules. The operator is entrusted with performance or monitoring of the most important and responsible functions in the system. Rational action is required of the operator in unforeseen circumstances, often under conditions of insufficient and, at times, unreliable information. The work of an operator, like that of the control system as a whole, proceeds on a real time scale, and this imposes special requirements as to its speed and accuracy.

Problems of optimization and planning of operator work with information models, preparation of specifications for information models, means of forming permanent and operational graphic-conceptual models of a situation have long since been the focal concern of specialists in ergonomics, engineering psychology and information display technology. At the same time, the content of this area of problems has undergone appreciable changes in the last 15 years. Research on the speed of perceptual processes, in particular, of information retrieval, has shifted to the background. Significant refinement of the quality of displaying information resulted in a decrease in number of studies dealing with the unequivocal nature of perception of symbolic and alphanumeric information. Much more clarity has been obtained in understanding of the technical-operational aspect of perceptual and cognitive processes. However, all this did not minimize the urgency of studying the routes for the design of information models and formation of conceptual models. The roots of these problems pertain to the very essence of the activity of operators of ASU's. In this type of activity, there is perhaps considerably more prominence than in others of a certain disproportion between the paucity of reflection and richness, complexity and multistratal nature of reflection of reality that man must reconstruct, analyze and use in accordance with the decision he has made. And in spite of the rapid development of display technology, this disproportion persists (if it does not increase with growth in scale and complexity of ASU's). Persistence of this disproportion leads to a change in the problems of perceptual and thinking processes that are studied.

Since the operator is dealing, more and more, with insufficiently defined space of possible problems, it often happens that he must retrieve, glean from the information model and, accordingly, reconstruct the most diverse objective content, different strata of reality. These strata may be external, characterizing for example the spatial arrangement of objects or isolated properties thereof; they may characterize the general functional properties of groups of objects, or functional (rather than only time and space) relations between different objects; finally, there may be situations that require working with systems of more or less interrelated categorial properties and qualities of objects, rather than with these objects proper.

Consideration of these circumstances, in which real operator work takes place, requires more intensive study than before of the motivational, goal-oriented in the broad sense, and personal aspects of perceptual and cognitive activity.

The sequence and possible depth to which an operator delves into a situation, its layers that are not directly visible, its meaning and importance are of considerable scientific and practical interest. Here, such a feature as time of penetration into these layers, time of construction of a GCM, which of necessity is special and, in a certain sense, biased, is also important. The time of enlarging upon the model or replacing it is also important. But, perhaps, what is the most essential is determination of orientation toward some objective content. The latter is determined by both the individual's problems and the objective content and, of course, means of retrieving and transforming its significance. This combination of circumstances leads to evolution (or change) of the GCM, i.e., evolution of cognitive products of activity, to a change in image of the situation, to setting new goals. Of course, the real object, its real objective content that determines the subject's action, is the main factor of this combination. At the same time, one should not underestimate the possible (and perhaps mandatory) effect of "reading into" the object the a priori experience and knowledge of the subject. The latter requires particularly attentive consideration of individual differences between people, of their possible preference for some strata of reality or other.

What we have stated about the objective content of operator activity confirms the thesis of its "dematerialization." This thesis should be interpreted in the sense that, at each given moment of his activity, the operator does not have an a priori conception of its concrete, objective content. He must retrieve it from the superfluous information model, construct the image of this objective content and, on this basis, set and reach concrete goals.

For expressly this reacon, operator work is sometimes called creative, and for expressly this reason it is so difficult to evaluate the efficiency of operator performance in MMS's, just as it is to solve pressing problems of optimization and planning of operator work.

Experience in developing and operating information models, as well as special analysis of operator work with them, enable us to formulate several of the most important features of information models.

1. The information model represents only the properties, relations, connections of controlled objects that are essential, that have a certain functional meaning, i.e., "which participate in the game." In this sense, the model reproduces reality in a simplified form, and it is always an idealization, to some extent, of reality. The degree and nature of simplification and idealization can be determined on the basis of analysis of MMS problems as a whole and analysis of the operator problems.

2. The model must be graphic, i.e., the operator must be able to receive information rapidly and without painstaking analysis. It is only under such conditions that he will not require much time for information processing of a decision, which includes the stages of formation of the GCM and, when necessary, formation of a model of the problem situation. The information model can be graphic in different meanings. It can, for example, provide a graphic idea about the spatial location of objects, i.e., it can be geometrically similar, to some extent, to their actual arrangement. In this case, the operator will have a graphic idea about such properties of controlled objects as the distance between them, their reference to a given territorial group, etc. If other signs are important to the operator, other properties of controlled objects must be presented graphically, for example, their reference to the same type or state. When the system is in operation, there can be periods when graphic idea is needed of some properties of controlled objects and periods when other properties have to be considered.

It is not always easy to obtain a graphic information model, since there are not uncommon instances when the objects of control, their properties and interactions do not in themselves have graphic features. In such cases, one has to solve problems that are similar to what is defined in scientific methodology as visualization of concepts.

3. One of the most important means of obtaining easy perceptibility, or "readability" of an information model is proper organization of its structure. This means that it is not collections or a set of information that is put in some order or other that must be represented in the information model, but that they must be in a specific and obvious interaction.

With a "good" structure or gestalt of an information model, the operator performs ordinary functions; impairment of "good" structure is indicative of occurrence of deviations from normal operating mode, which require immediate intervention of the operator. A good structure provides for rapid and correct perception of the situation as a whole. Deviations from it are perceived by the operator as potential problems or conflicts, and compell him to make a detailed analysis of the situation in order to detect the source of conflict and find the means of eliminating it. One of the means of achieving a good structure is proper arrangement of the information model. In this sense, development of the information model is a task that is equivalent, to some degree, to the task of good layout of a painting. Just like a well-composed painting, the information model can help perceive the situation as a whole, if it is not overloaded with details that impair integral perception. An important task for an artist is to select what is essential and typical, what enables him to convey his idea to a viewer with utmost effectiveness. In the very same way, when creating an information model, it is extremely essential to select functionally significant information and informative data that must be presented to the operator. This applies equally to reflection of conflict situations, awareness of which is made easier upon encounter of contradictory images, tendencies, properties, etc.

4. It is easier to perceive a situation as being problematic if the following is provided in the information model: Reflection of concrete changes in properties of situation elements, which occur when they interact; in such cases, the changes in properties of individual elements are not perceived separately, but in the context of the situation as a whole; moreover, a change in properties of one element is perceived as a symptom of change in the situation as a whole, and this prompts a search and identification by the operator of a given set of symptoms; reflection of dynamic relations of controlled objects, where the relations and interactions must be reflected in the information model as they develop; it is permissible and useful to also have an exaggerated or amplified reflection of trends in development of situation elements, their relations or the situation as a whole; reflection of conflicts into which enter the elements of the situation.

5. Information about objects of control is not displayed to the operator in its natural form, but it is coded. The problem of creating a special language, understandable to man and, at the same time, usable by the machine, the problem of matching human and machine "inputs" and "outputs" becomes a particularly important one.

When constructing an information model, it is imperative to find the most effective code, i.e., the system of symbols (which we shall call "alphabet" of the code in question), with which information is presented about controlled objects. The choice of coding system is closely related to the possibility of rapid interpretation of information presented to the operator.

6. The volume of information of one kind or another that can be well-assimilated by the operator cannot be arbitrarily set. It must be determined for specific working conditions or already on the basis of existing

quantitative evaluations of operator work, or by means of a special experiment. If this volume of information has been determined, along with the chosen coding system, it helps form an idea about the degree of complexity of the information model that is permissible under given conditions.

The degree of complexity of an information model is determined chiefly by the requirement of dynamic function.

The above description of properties of information models does not presume to be complete. The properties of information models that we have mentioned can be considered in the course of a specific design project to different extents, depending on the prevailing operator function (detection, retrieval, problem solving, execution, etc.).

What we have stated above concerning the properties of information models applies equally to instances when all of the main features of the models are determined at the MMS designing stages and when operators have considerably greater freedom in working with data stored in computer memory, and themselves participate in construction of the information model.

Thus, when constructing an information model for a control system, one must take very many factors into consideration. Of course, we cannot presently mention all of the specifications that must be considered in designing and constructing information models. However, even now, we can suggest the following procedure for such construction:

1) Determination of problems for the system and order in which they are solved
2) Determination of sources of information, methods of solving problems, time spent to solve them, as well as required accuracy
3) Listing the types of objects for control, determination of their number and other parameters of system operation, which must be considered when solving problems
4) Making lists of features of control objects of different types, consideration of which is necessary to problem solving
5) Distribution of objects and tags according to importance; choice of critical objects and tags which must be considered first of all
6) Distribution of functions between machines and operators and, in particular, determination of the following: number of levels of control and degree of complexity of each of them so that the carrying capacity of operators is not exceeded on each level; types of information models on each level; automatic equipment needed with the planned structure of the system.

In a number of instances, the first steps of the process of system designing must be repeated several times in order to come successively closer to the optimum variant taking into consideration the economic aspect of construction of the system.

After the first stages of work to design a system have been completed, one can turn to the next ones:

7) Choice of coding system for control objects, their states and tags for information models on different levels of control, that is optimal from the standpoint of functional capabilities of operators working in the system
8) development of general composition of information models that would provide for predominant distinction of the most important objects, and states and tags that are critical to system operation
9) Determination of the system of executory actions of operators, which must be performed during the solving process and after it (request for information, transmission of reports, instructions, etc.)
10) Development of a mock-up of the game situation and testing on it of the effectiveness of the chosen variants of information models and information coding systems. Time and accuracy of operator work, which must conform with the conditions of proper operation of the system as a whole, serve as the criterion of efficiency when working on the mock-up
11) Change in composition of information models and coding systems on the basis of results of experiments, and testing the efficiency of each new variant on the mock-up
12) Determination on the mock-up of the required degree of operator training, methods of training and optimum mode of operator work in the control system, in accordance with the speed and accuracy requirements of operator work
13) Preparation of instructions for operator work in the game control system

After selecting and testing the optimum variant of information model and information coding system, one can begin to work on the engineering design of display devices, that permit presentation of information in the required form to the operator. The same applies to logical-information machines, for which one must prepare algorithms for information processing and rendering it in a form that assures perception on a high operational level.

At all of the stages of work pertaining to the design of information models, specialists in several fields related to development of control systems must work together: systems analysts, specialists in research on operations, mathematics and developers of display devices, engineering psychologists and ergonomists.

The procedure suggested above is only general in outline. It can change, depending on the specifics of particular control systems or differences in operator functions within the same control system. Much of what we are dealing with here is considered intuitively when developing control systems, but usually far from adequately.

2. Spatial Characteristics of Visual Information

Three groups of factors are considered in designing and operating means of display: 1) location of displays in the work place and operations rooms; 2) optimal dimensions of symbols and their elements in different display systems; 3) optimum arrangement of symbols on display devices.

Arrangement of display devices in operations room: The arrangement of displays in the observer's field of vision should take into consideration optimum angles of vision and zones for the observer.

With regard to objects with complex configuration, as well as perception of a three-dimensional images and those in perspective, the optimum angle of vision in relation to the horizontal plane is 30-40°. To perceive a flat image, as compared to a simple sybmolic display, an angle of vision of 50-60° is recommended, which covers the region of vague discrimination of shape (within this angle, the observer notices occurring changes with peripheral vision, then shifts the eyes to it for accurate examination of the object). The maximum angle of vision with concurrent eye and head movement is 180°. However, when displaying information with the requirement of very rapid processing thereof, the permissible angle is 90°.

In the vertical plane, the optimum angle of vision is 0-30° in relation to the horizontal (15° above and 15° below the normal line of vision). The normal line of vision corresponds to the most comfortable position of the eyes and head when examining objects, and it is at an angle of 15° below the horizontal line of vision. In the vertical plane, the maximum angle of vision when only the eyes move is 70° and with concurrent eye and head movement it is 90° above and 55° below the horizontal line. The height and width of indicators and their proportions are designed in accordance with these angles. With specified dimensions of indicators, calculation is made of the position of observers in the horizontal and vertical planes, angle of inclination of indicators, mutual location of indicators at the work places and displays for collective use in the operations room.

Large screens, which are at a considerable distance of operators, are placed vertically. Proceeding from the correlation between vertical and horizontal angles of vision, the width of the screen is about twice its height. With a screen less than 10 m in width, the ratio of screen width to height is set at 1.3:1. The best place for the observer to be is at a distance that is 2-2.5 times greater than the width of the screen. Maximum distance between him and a large screen is 8 times greater than its width. The location of the screen must be determined with due consideration of its relation to the observer's line of vision. The accuracy of image perception depends on the angle at which it is viewed. The optimum angle of observation is ±15° in relation to the screen's normal. To examine an image from the side, the permissible angle of vision is 45° in relation to the screen's normal.

The general specifications for organization of optimum zones of observation also apply to location of displays on the consoles. Additionally, consideration is given to the need to simultaneously look at collective displays and indicators at work places. Accordingly, the location of cathode-ray tubes, television sets, displays should be below the line of vision. For a seated operator, the distance between the floor and line of vision is 1240-1250 mm.

The optimum location of indicators is in the vertical angle of vision 45° below the horizontal line of operator vision.

For optimum observation conditions, the plane of the face panels of the indicators should be close to perpendicular in relation to the line of vision. This is obtained by tilting the face panels. On the basis of experience in designing operator work places, the inclination of tubes is 0-4 to 0-20° from the vertical plane. Spatial arrangement of display devices cannot be designed without consideration of illumination engineering features of indicator devices, and first of all the coefficient of brightness, which determines the visible brightness of an image with change in spatial position of the observer.

Optimum dimensions of symbols and their elements: The optimum dimensions of symbols conform with the concept of operational thresholds of perception, with which maximum accuracy and speed of human perception and recognition of incoming information are provided.

The optimum size of symbols displayed on indicator devices is calculated with consideration of brightness of the symbols, degree and type of contrast, complexity of graphic outline of symbols and use of colors. The displayed symbols are divided into two groups: alphanumeric alphabet and alphabet of conventional symbols.

The permissible size of letters and numerals, considering only accuracy of reading against the background of other symbols, is 18-20'.

With concurrent consideration of accuracy and speed of recognition, the optimum symbol size is 35-40'.

For numerals to be readable, there must be optimum proportions between the main parameters of the symbol: height, width, and thickness of outline. The thickness of lines for reverse contrast symbols is one-tenth the height of the symbol. Symbols viewed in slits [spaces] can have thinner lining, one-thirtieth, one-fortieth. This is considerably smaller than the figures recommended for proportions of direct contrast symbols, by virtue of irradiation that enlarges the visible thickness of lines and reduces the visible space between symbol elements. However, in a number of cases, it is not desirable to reduce the thickness of symbols for a number of reasons. One of them is related to the need to use color as the optimum code for displaying information. Proper identification of color is possible only when the dimensions of the color fields are not smaller than critical values. With further decrease, there is severe distortion of color of surfaces. With $\alpha<15'$, yellow, green and purple colors change to blue-green, dark-gray and brown, respectively. Yellow and blue are the most susceptibe to change, and with $\alpha<2'$ they are perceived virtually as achromatic. For this reason, when using colors, the optimum size of symbols is calculated on the basis of the required line thickness to transmit the color with adherence to symbol proportions for direct contrast.

With these proportions, a symbol 35-40' in size with $K>60\%$, provides for good discrimination with the use of the main color codes.

The reciprocal position of lines forming the symbol affects readability of the symbols, in accordance with the parameters of visual acuity. MacWorth type, in which the lines in symbols are at an angle of 45°, is considered the best of numeral outlines, as well as Berger type, in which letters and numerals are made up of straight lines.

For an alphabet of arbitrary [conventional] symbols, the optimum size of a symbol that provides fastest and most accurate perception depends on the complexity of their configuration. For symbols with simple configuration consisting of outlines--triangle, square, trapezium, oval, etc., the operational threshold of recognition is $18\pm1'$ for the largest side of the outline. To determine the size of complex symbols, one must consider both the size of the symbol as a whole and the size of its parts, as well as the smallest distance between them. For symbols of average complexity, with elements inside and outside the outline, the angular dimension of the symbol should constitute $21\pm1'$. The smallest part should be 4-5'. If the symbol is complex, with external and internal details, it is difficult to recognize, and error-free work can be done with large symbol size, $\alpha = 35\pm2'$. The smallest details should be 6' in size.

The optimum proportion between the size of a conventional symbol and numerical information pertaining to it is 2:1 or 1.8:1.

Symbols made up of discretely lit elements: Special-purpose cathode-ray tubes are used to display alphabets of signs. The displayed signs are composed of discrete lighting elements, by means of point matrices or line image. For them, determination is made of number of elements in the pattern, size and area of pattern elements, distance between symbol elements. The optimum size of the symbols is determined by the features of operational work and conforms with the requirements made of printed symbols.

The minimum size of a symbol depends on the number of elements required to recognize it. For the grating method, the minimum number of lines for letters and numerals is 10. For a dotted matrix, the number of dots is the same.

Readability of symbols formed by means of dot matrices and the grating method is the same; however, operators prefer dot symbols.

Estimation of the speed and accuracy for parameters of the required number of breakdown elements for letters in the Russian alphabet and numerals revealed the advantage of 6×9 and 5×7 matrices with the grating [zebra-type] method of generation of symbols and 8-16 elements with the functional method.

One should strive for indiscernibility of elements of the pattern: dots in matrix, grating, etc.

In order to obtain a continuous pattern the distance between the edges of adjacent spots should be less than 1'. To obtain images with the illusion of continuous brightness, conditions must be provided, under which the distance between spot centers is less than 1'.

If the discrete structure of a symbol is noticeable, readability of the symbol is determined by the perceived brightness of elements of the image, in addition to the above-mentioned factors. The perceived birghtness does not depend on the size (area) of elements if they constitute at least 2'. However, with smaller sizes, the perceived brightness is determined by the product of multiplying image area by intensity of light flux (law of Ricco) and, consequently, with decrease in size of lighted elements it will weaken.

Optimum characteristics of symbol arrangement: In the course of processing signals, the eye moves from object to object, with subsequent fixation. Meaningful information processing takes place at the moment of fixation, while the eye movement provides for the successive processing of perceived information.

Specifications for arrangement of symbols and their reciprocal location in monitored space are formulated in accordance with the patterns of these two stages of eye "behavior."

The specifications as to layout of symbols are determined by the size of the working field of vision and resolution capacity of the eye's motor system. The size of the operational field of vision limits the number of objects that can be submitted to instant (200-300 ms) visual information processing.

The resolution capacity of the eye determines the density of arrangement of objects or instantly perceived groups.

In display practice, there are two possible means of presenting information: organized and "chaotic."

The first refers to formulary and tabular means of organizing symbolic information.

The formulary ["formulyar"] refers to letters, numerals and symbols that code data about controlled objects and that are combined in a compact group.

The formulary should not exceed 4-5 numerals, according to the size of the operational field of vision. The optimum number of digit positions in the formulary is 12. This number was determined on the basis of minimal number of fixations to read the formulary and minimum time for selection of different types of communications and decoding information coded in numerals and letters.

For optimum distinction of information coded in the formulary in certain digit positions, there must be specific distances between its elements.

The following spaces are recommended between formulary elements: at least one-quarter the height of the conventional symbol between the latter and formulary referable to it; one-half the width of the symbol between different symbols in the formulary; one-half the height of the symbol between lines.

The tabular method consists of arrangement of symbols in columns and lines that have independent meaning. The required data are read off by means of errorless determination of coordinates of information extracted from the table.

Accurate and error-free reading of information on the table is effected when its organization is optimum, with regard to overall size of the table (in angular dimensions), number of columns and lines, total number of symbols in the table, density of vertical and horizontal arrangement of symbols and degree of homogeneity of the table.

With the usual methods of working with numerical tables, the independent part of the table should not be larger in size than the operational field of vision. The density of symbols must be higher than the level that induces oculomotor noise.

The permissible density of digits in the table depends on the overall dimensions of the table, from which information is read. The smaller its size, the higher the density at which one can place the numerals with retention of the mode of rapid and accurate reading.

The optimum proportion between digit density and table size, with which it is possible to accurately and rapidly observe or find numerals according to set coordinates is 3° with density of 10', 5-7° with density of 15' and 10-15° with density of digits of 20'. On larger tables, it is recommended that digit density constitute at least 60'. Errorless work is done with great strain when density is 40-50'.

Conformity with the dimensions of the operational field of vision is achieved by dividing the overall field of the table with lines or other means that minimize its homogeneity.

The following intervals are recommended: the space between symbols (digits) should equal the thickness of the outline; the space between columns (numerals) should be half the width of the symbol to a distance equal to the height of the symbol.

3. Brightness Characteristics of Visual Information

Evaluation of optimality of brightness includes standardization of brightness level and gradients thereof in the observer's field of vision in order to achieve the preset parameters of efficiency of processing visual information. In order to assess the quality of an image on indicator devices, standards are set for contrast, contrast or interval of brightnesses, required to transmit the specified number of gradations of brightness and provide a distinct image, as well as level and interval of brightnesses for proper transmission in the image of luminosity characteristics of displayed objects. Special problems are solved with the use of brightness as a code.

Brightness level: Optimum brightness refers to intensities that assure maximum manifestation of contrast sensitivity, which is the main function of the eye. Minimum values of threshold contrast are an index of maximum manifestation of this function. Table 5 lists luminosities for objects with different angular dimensions, starting with which maximum contrast sensitivity of the eye is provided.

It is important to display practice that, at the level of optimum brigthness, the existing "stock of stability" assures stability of efficiency in detection and discrimination with noise-generation factors. The latter refer to both instrumentation noise, which lowers contrast of the image, as well as "cluttering with noise" the main image by the cartographic background, auxiliary lines and color fields. With brightness that provides high contrast sensitivity, one can reduce, to some extent, the brightness of the image without deterioration of discernability. The listed values of optimum brightness apply only to operations of detection of objects of simple configuration with a threshold reliability for detection probability of 0.5. When discerning objects of complex configuration, with the requirement of highly accurate recognition and very rapid data processing, correction coefficients are used, which increase the brightness values obtained for detection problems.

The brightness of the background (for direct contrast objects) assuring maximum acuity of discrimination (S = 2.5) constitutes 10^4 cd/m^2. When distinguishing complex objects, optimum acuity of vision is reached with background brightness of 3000 cd/m^2. However, there is not such drastic change in visual acuity with decrease in brightness. With brightness of 300-200 cd/m^2, acuity constitutes 90% of its maximum. Drastic decline of acuity is observed when departing from the range of brightness of daylight vision, i.e., $B<10$ cd/m^2.

Table 5.

Parameter	Angular size of object (min)						
	1	2	3	5	10	50	150
Minimum threshold contrast, S	0,12	0,045	0,03	0,018	0,012	0,01	0,008
$B_{opt.}$, nit	1·10[illegible]	0,64·10[illegible]	0,3·10[illegible]	0,2·10[illegible]	50	10	8

When selecting brightness, one should take into consideration the sign of the contrast of the image. Acuity increases with negative [reverse] contrast when brightness increases to 30-31 cd/m^2, and with further increase acuity diminishes due to irradiation.

Correlation between brightness levels in field of vision: When setting the optimum range of brightness levels present at one time in the operator's field of vision, one must provide for a gradient close to the accommodation level. Brightness that is in the range of blinding levels or indistinguishable black lower drastically the efficiency of operator work.

The maximum permissible gradient of brightnesses in the operator's field of vision should not exceed 1:100. The optimum correlation between brightness levels in the operator's field of vision assuring a high level of contrast sensitivity and rapid discrimination constitutes 20:1 between the light source and immediate vicinity, and 40:1 between the lightest and darkest sections of the image.

gradations of brightness and image quality: For transmission of an image of an alphabet of symbols, conventional pictorial situation and transmission of real objects (television, movies), the most important characteristic is the number of elements or signs needed to recognize objects of different classes.

This number is 4-10 for recognition of the alphabet of alphanumerical symbols. For more complex patterns it constitutes 12-17, while recognition of some objects requires distinct discrimination of up to 40 tags.

Depending on the type of image, these identifying elements are transmitted by a different number of gradations of brightness. The minimum number is 2, with transmission of an image. With this number of gradations, sign or symbol communications are illuminated: dark symbols on a white background (direct contrast) or, on the contrary, light ones on a dark background (negative contrast). In this case, the quality of the image is assessed by the level of contrast (K), which is calculated as the ratio of difference between object and background to the greater brightness.

Contrast of up to 20% is considered low, to 50% average and over 50% high. The recommended range of contrast is from 65 to 95%; 85-90% is the optimum contrast. Contrast above 90% should be used when utmost clarity of image is required and total working time is short. Contrast of 85-90% is preferable when working time is long.

When real objects are displayed by means of television or motion pictures, it is important to accurately transmit the correlation between brightness of object details proportionately to their reflection coefficients. It is mandatory to estimate the number of gradations of brightness and determination of steps [pitch] when moving from one gradation to another.

To transmit large objects with smooth color transitions, at least 15-40 gradations are required to conform with the coefficient of reflection.

One can provide the specified number of brightness gradations only if the image has an adequate level of contrast (β), i.e., with the range of brightness levels within which these gradations are located.

The minimal permissible contrast providing for a satisfactory image is in the range of 1:10.

The required contrast of an image is related to the content of information displayed and type of contrast. For transmission of a complex, half-tone image with preservation of details, contrast must constitute 1:100. Printed images or those formed by hashmarks require 1:25 contrast. The contrast level depends appreciably on whether the background is lighter or darker than the displayed objects. For s mbols with negative contrast, the permissible contrast is in the range of 5-10, because of the need to accomodate to the low brightness level. With high levels of contrast the illuminated symbols appear as bright light sources.

Minimal permissible contrast, when reading symbols against the background of a noise-generating and single tone image, is determined with consideration of the criteria of efficiency of reading such information. If only accuracy of reading is considered, the ratio of brightness of useful image and brightness of noise should be at least 2:1. With concurrent consideration of speed and accuracy of recognition, this ratio increases to 7:1, 9:1.

Image contrast decreases with external illumination, and this increase is all the more significant, the lower the brightness of the screen and the higher the brightness of external light. The level of external light should not exceed 3-10% of screen brightness.

Evaluation of quality of an image includes determination of the number of gradations perceived by the eye and comparison thereof to the number of gradations of brightness transmitted on the indicator devices. Real display conditions--low brightness of image, presence of noise--make it impossible to discriminate between the displayed number of gradations of brightness because of diminished sensitivity of the eye.

Thus, the estimated number of distinguishable gradations for a television image is 95-100. However, because of the gradients of brightness in the observer's field of vision and need for reaccommodation under such conditions, the eye discerns no more than 30-35 gradations; with noise, the number of gradations distinguished on the best metal-coated screens is 17, while for ordinary television screens it does not exceed 8-10.

The number of brightness gradations distinguished by the eye is determined on the basis of contrast sensitivity under given conditions, using the following formula:

$$m = \frac{2.3 \cdot \log \beta}{K_{thr.}}$$

where m is the number of brightness gradations, β is image contrast and $K_{thr.}$ is threshold contrast under given observation conditions.

$K_{thr.}$ is determined from the appropriate curves, with consideration of brightness of accommodation, angular size of objects, type of contrast, uniformity of distribution of brightness levels in space.

Brightness coding: When information is transmitted to display devices, where brightness emerges as a code, the number of gradations is limited by man's ability to absolutely evaluate each of the degrees of brightness.

The range of such evaluation is 3-10 gradations of light, including the level of complete darkness.

For this reason, 5-7 gradations in the contrast range of 10:1 are used on display devices of the television screen type, which transmit the secondary situation (i.e., free of noise). If the brightness level is a code for transmission of quality characteristics of information (for example, importance of objects), the limit is 4 gradations of brightness, while 2 gradations are used the most frequently.

4. Time Characteristics of Visual Information*

The main distinction of visual perception is that there is a static [inertia] element to eye function.

The practical implications of this distinction of sight are manifested in two aspects. The first is related to determination of exposure time of visual signals for consistency of perceived intensity of the signal. The second is related to determination of time intervals to perceive the separation between signals following one another and optimum perception of each of them or, on the contrary, determination of intervals to perceive merging of successively presented signals.

In both cases, the time of visual inertia is the reference point for calculations.

Inertia time is determined by the brightness of the background. For brightness exceeding 100 cd/m^2, inertia time may be taken as 50 ms.

For levels of brightness, with which an operator works on all forms of display devices, exposure time for perception of unchanging intensity of a signal should be at least 50 ms.

For the perception of flashing signals as being fused, one should deliver flashes at a frequency equal to or greater than critical flash [flicker] frequency (CFF).

One must take into consideration flash frequency to produce a good image on different display devices based on discrete signal technology (television tubes, cathode-ray tubes, films). Flashes fatigue the eyes and have an adverse effect on quality of operator work.

CFF is related to the frequency and relative duration of the light phase. With increase in duration of the dark period (on-off flash ratio) from

*In this section, the time characteristics of visual signals are discussed only as elements of variable visibility.

0.35 to 0.5 at brightness levels of 2.5÷250 cd/m^2, the CFF increases by 3±6%.

Flickering increases with increase in angular size of flashing fields. With regard to a television screen, the CFF is calculated for the entire tube size and size of the image.

The frequency of changing information should be at least 40 Hz when projecting fields greater than 2-4° and field brightness is of the order of 30-100 cd/m^2 (which corresponds to brightness levels of the television image).

Within the range of 10 to 55° of change in angle of observation, CFF is proportionate to the logarithm of angular size of the field of vision, which requires a 15 Hz increase in flash rate.

The characteristics of CFF for the technical conditions of presenting symbolic data on screens and cathode-ray tubes are related to the small angular dimensions of flashing fields of up to 1°. When the symbol is up to 1° in size, CFF increases from 14 to 35 Hz with increase in brightness from 1 to 120 cd/m^2. A decrease in angular size of the symbol from 1° to 24' alters the CFF from 24 to 19 Hz (with brightness of 50 cd/m^2).

When projecting symbols with angular size of 5÷15', the CFF may be reduced to 20 frames/s.

However, CFF is not determined by the size of separate symbols, but by the overall area of the image.

A change in configuration of a symbol (which also means a change in area of illuminated image) affects the CFF just like a change in angular dimension of a flashing symbol.

5. Coding of Visual Information

One of the important problems is coding information, which refers to the operation of equating symbols or groups of symbols in one code with the symbols or groups of symbols of another code. Code refers to a system of conventional symbols for transmission, processing and storage (memory) of diverse information. At the present time, general ergonomic specifications have been worked out for systems of coding visual information.

When forming a system of coding, objects and their features are divided into classification groups. For this purpose, similarity and differences between objects are determined, they are distributed according to importance, and determination is made of the classification base. The code alphabet is chosen with due consideration of the nature of transmitted information and problems solved by the operator, on the basis of systems of knowledge acquired by man through experience. Depending on the nature and volume of transmitted information, determination is made of the desirability of using a one-dimensional or multidimensional code. The code base is selected according to number of coded objects and their characteristics. It should consist of a minimal number of symbols. The code base is determined with due consideration of absolute sensitivity of the eye (top and bottom absolute threshold), differential sensitivity of vision to various types of alphabet and exposure time. The code base for different types of alphabet should consist of the following parameters: size--5, spatial orientation--8, length of line--6, orientation of line--4, number of points [dots] (when presentation time is limited)--5, alphanumeric alphabet--unlimited number of combinations, brightness--4, color alphabet--11, flash frequency--4.

Multidimensional coding is used to relay information about several features of an object. One can use combinations of different alphabets in the structure of a multidimensional code: shade and color, shape and spatial orientation, size, brightness and flash frequency.

When symbols are grouped in code (formulary), one should give preference to mixed alphabets in the code. The structure of code designation should be permanent. It is preferable for the extreme signs of a code designation to relay the most important information. The optimum number of signs in a code designation is 8, maximum number of signs is 12 and, in some cases, up to 20.

When developing code signs one should be governed by the following theses for encoding: The main classification sign of the object should be coded by the outline. The sign must be well-distinguishable (with adequate angular dimension and brightness) and consist of a closed figure. There must be an optimum quantitative correlation between sign tags and object tags in the alphabet. The sign should contain the main and additional details. Additional details should not intersect or distort the outline of the sign (signs expressing cancellation of information, inhibition of some action, termination thereof, etc., may be an exception). When designing the signs, preference should be given to internal details over external ones. The details of code signs must be standardized.

One cannot use the following as identifying tags of signs within the same alphabet: number of elements in the sign (signs designating the multiplicity [set] tag without precise quantitative features, for example, those reflecting conceptions of "little/much," "single/group," are exceptions); distinction of signs according to positive/negative tag; distinction of signs according to tag of direct mirror reflection (with the exception of cases when this is needed to display spatial orientation or direction on the principle of "up/down," "to the left/right," "forward/back," etc.).

Signs of symmetrical shape with the same orientation are used in the alphabets: the outlines of the signs should be directed as much as possible in conformity with the main spatial axes, horizontal and vertical.

One should be governed by the following factors in choosing an alphabet: For coding various qualitative and quantitative features of objects one can use different types of alphabets: shape, size, spatial orientation, length and orientation of line, number of dots, letters, numerals, brightness, color, flash frequency.

Shape is used to code the class and type of object.

Size coding is used to relay information, establishing conformity between the area or linear size of the sign and characteristics of the object (size, distance, height, etc.), and it is desirable for the size scale to change in geometric, rather than arithmetic, progression.

Spatial orientation is used to relay information about the direction of movement of an object, deviation from course, etc.

A change in spatial orientation of asummetrical figures is obtained by turning the figure in the observer's field of vision. For symmetrical figures, thickening of one of the lines of sign outline is used as the tag for spatial orientation.

Length and orientation of the line are used to relay information about speed and direction of movement of the target.

The length of the line should not have more than four gradations. It is desirable to make a dash line, in which case the speed is determined by the number of graduation [scale] marks. For the sake of simplicity in counting, one should separate the dashes in groups of 2, 3 or 4.

Auxiliary, stenciled [pattern] grids are used to increase accuracy of determination of direction of a line.

The number of dots is used to designate the number of objects.

When reading dots within short intervals (of the order of 0.1 s), one should not display more than five at a time. To increase the accuracy of estimation of number of simultaneously exhibited dots, one must adhere to uniform spatial orientation thereof.

The alphanumeric alphabet is used to relay information about discretely changing quantitative parameters of objects, as well as to designate classes or types of objects.

To rule out the probability of confusing signs, typical tags are made prominent to distinguish the signs from one another. It is imperative to maintain optimum correlations between the main parameters of the sign: height, width, thickness of line (according to GOST 2930-62).

Brightness of signs is chosen with consideration of general lighting under specific working conditions, frequency and range of change in lighting, brightness gradients in the operator's field of vision and luminosity contrast.

The color alphabet is used to relay information about the state or significance of objects.

Flashing frequency can be used to attract the operator's attention:

Threshold flashing frequency	4-6 Hz
Flash frequency of warning signals	0.5-1 Hz
Flash frequency for emergency [accident] signaling	5-6 Hz

There should be no more than three simultaneously flashing signs.

One should avoid distortion of perception of the outline of a flashing sign. For this purpose, it is desirable to have only part, rather than all, of the signal flashing.

The requirements for use of a color alphabet consist of the following: Preference should be given to green, red, light blue, yellow and purple in the alphabet. The total number of colors can be increased, if the designations change not only in color tone, but in brightness. The signs of the alphabet should be well distinguishable with accurate color recognition.

A color code is used when there is white illumination, since the visible color depends on general illumination. The permissible brightness of color signs is as follows: minimal--10 cd/m^2, recommended 170, and for reflected light, as well as dark accommodation, 30-70. The optimum angular size of the color sign is 35-45'.

Colors for alphabet signs are used in accordance with the indications given in Table 6.

In order to make particularly important information within the alphabet particularly prominent (for example, information that requires urgent decision making), an additional color is used. One can use red and blue to code information containing a report that one out of two (yes, no) equally probable events has occurred.

Table 6.

Category of information	Recommended color code	
	main	ancillary
Warning information of informative nature, contains data about the general situation (with the exception of accidents) and recommendations for taking steps, leaving to the operator the right to choose the final decision	Yellow	White
Instruction-giving information of a command nature, requires or permits performance of strictly defined action This category may also include verifying information indicating the proper function or readiness for operation of some devices or other	Green	Blue
Inhibiting information of an emergency (accident) nature, imposing strict restrictions on performance or inhibition of some actions or other Indicates that some checked device or other is not ready for operation or is malfunctioning	Red	Orange

6. Requirements Referable to Visual Indicator Devices

The displays should be so designed that malfunction or failure thereof is immediately apparent to the operator.

Trade marks and names of the plant or manufacturing firm, as well as other designations unrelated to functions of the indicator device, should not be on the face of the panel.

Indicator devices should be so designed and arranged that the operator can read information with the required accuracy.

Indicators should be designed and arranged in such a manner as to avoid loss of information due to reflection of external light from the indicator surface. In some cases, special devices are provided to prevent worsening of information perception conditions. Such devices include, in particular, shields and hoods, that protect indicators against direct sunlight.

Lighted indicators: There are three main types of indicators with lights: lighted panels with one or many inscriptions carrying information in the form of words, numerals, symbols or abbreviations; simple indicator lamps (signal and others); panels with illumination that display information about readiness of a system.

The indicators with light are used to display qualitative information needed by the operator (mainly information requiring his immediate reaction, or to call his attention to the status of the system). Such indicators may sometimes be used by personnel who perform technical maintenance and adjustment.

Absence of a light should not be used to designate such concepts as "readiness," "within permissible range," or the command to "continue," as well as to designate "malfunction," "beyond permissible range," or the command to "stop action"; however, absence of light is permissible to indicate that the power is turned off (for example, to display the inscription "power on"). A change in status of the displays should reflect changes in functional state of the system, rather than only the results of action of control elements.

Light signals for warning and alarm, as well as those used to display the state of equipment complexes in the system, are placed separately from the light signals that show the state of various components and units.

If a lighted indicator device is connected to a control element, the indicator light should be so placed as to be unequivocally related to this control element and visible to the operator working with it.

Indicators of critical functions must be located in the zone of optimum visibility.

Indicator lights that are used seldom or exclusively for purposes of technical maintenance and adjustment should be covered or invisible when operating the system, but within easy reach.

If the indicators are intended for use under conditions of changing illumination, there must be provisions for brightness adjustment in them. The range of brightness adjustment should assure good distinction of information reflected on the indicator under all expected lighting conditions. In any case, they should not appear to be on when they are off, or perceived as off when they are on. In some manuals and standards for indicators using incandescent lamps, it is recommended that one use lamps with spare incandescent filaments, or double lamps, so that in the event of failure of one filament the intensity of light would diminish, thereby indicating the need to replace the lamp, but not to such an extent as to prevent the operator from working.

It must be possible to test indicator lamps. It is desirable for their design to provide for testing of all indicator lamps at once. Panels containing three or less lamps may have individual buttons to test the lamps. If rapid dark accommodation is an important requirement, the means are provided to reduce brightness of the entire indicator circuit during testing.

It is desirable to be able to remove the lamps from the front of the indicator panel without using tools or any other rapid and convenient method. The indicator circuits are so designed that the lamps can be removed and replaced without turning the power off, without the danger of damage to components of the indicator circuit and without danger to service personnel.

The indicator screens or indicators with inscriptions (indicator glass) should be so designed as to prevent accidental misplacement of the glass plates.

Lamps with inscriptions have gained wide use; in most cases they are preferable to simple indicator lamps. The lamps with inscriptions can be color coded, as well as coded by size and flashes. Lamps with inscriptions that are intended to designate damage caused to equipment or injury to service personnel (flashing red light), to warn about an impending danger (yellow) and for the overall test signal should be appreciably larger in size and, if possible, brighter than others. The inscription on the lamp should be readable, regardless of whether the display is turned on or off.

Indicators with numerous inscriptions (plates with inscriptions located one over the other) must be designed with consideration of the following requirements: when the back inscription is lit up it should not be obscured by the front ones; the back plates with inscriptions are so placed as to minimize parallax;* the back inscriptions must have the same apparent brightness as the front ones.

Simple indicator lamps should be used when the design specifications do not permit the use of lamps with inscriptions. The distance between lamps should be sufficient for unequivocal designation thereof, proper interpretation of information and convenient replacement.

Pointer indicators: There are two types of such indicators, with moving pointer and stationary dial, with stationary pointer and moving dial.

Depending on the nature of set problems, pointer display devices can be used either with or without control knobs.

*Parallax is the perspective (apparent) displacement of an examined object due to change in point from which it is observed.

Pointer indicator devices with knobs are used to set a specified parameter, as well as to replace the pointer when it deviates from the set value. In this case, the better type of indicator is one with a moving pointer and stationary dial; the best form of dial is a horizontal one. One can also use round dials. The choice of dial depends on concrete conditions: size of panel, number and shape of other instruments, etc. Pointer indicators with knobs are also used to monitor the object by means of continuous change in position of one pointer with movement of another (tracking operation). The best type of indicator for such tasks is the one with moving pointer and stationary dial, and the best form of dial is round.

Pointer indicators without knobs are generally used to solve the following problems:

a) Quantitative reading. The operator is concerned with the exact numerical values of the parameter measured. However, the best instrument is a counter with digits, since the operator perceives digital data faster and with fewer errors
b) Qualitative reading. It is not absolute readings, but information about change in some parameter of the object studied or tendency in development of a process (increase or decrease in given size, etc.) that the operator is concerned with. Use of an indicator with moving pointer and stationary dial provides the best accuracy and speed of reading; a round dial is the best.
c) Testing (monitoring). The operator is concerned only with control readings, i.e., he has to know whether the equipment is operating within the established range or not, rather than quantitative data. For this purpose, a stationary dial is recommended, with moving pointer, and a round dial is best.
d) Comparison of readings. This operation requires exceptional accuracy, and for this reason it is also desirable to use counters.

In selecting a pointer indicator, one must know the time mode in which it will be used. With short exposure time (less than 0.5 s), the readings of an instrument with moving dial and stationary pointer are more accurate: in this case, reading conditions are close to the conditions when reading from a counter. However, with increase in exposure time, preference is given to instruments with moving pointer and stationary dial.

The reading speed and accuracy depend largely on the shape of the dial. A round one yields the best results, followed by semicircular* and rectilinear horizontal dials; vertical dials are the worst.

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*Round refers to a curved dial with a curve angle of about 360°; semicircular refers to a curved dial with an angle of about 180°.

When taking readings on the same dial, the results are different, depending on the segment of the dial from which reading begins. Round dials provide the best results for readings in the central top sector, while horizontal ones are best when reading in the central part of the dial (where they are superior to round ones); but as one gets closer to the ends of such dials, the reading speed and accuracy drop significantly.

When selecting a dial, one must also take into consideration its proposed length. If one has to install an instrument with a long dial on the control panel, the following recommendations are offered to increase reading speed and accuracy: there should be several pointers for the dial, one for precise reading and one or several more for reading that does not require accuracy; a subdial [smaller dial] is provided on the main dial for more accurate readings; the dial is combined with a counter. Such combined indicators are desirable when performance of a task requires both qualitative and quantitative reading of information.

The shape of the dial should be selected with consideration of the nature of information for which it is intended. Thus, for instruments used to monitor parameters of depth, height and temperature, vertical dials are best; for depth indicators, 0 position should be located near the tope end of the dial and for altimeters, near the bottom end.

The accuracy of reading dials depends on the size of the dial, distance from which it is read and interval between marks.

Instrument dials are graduated using lines of specific sizes. These marks are subdivided into main, medium and small. Reading accuracy increases with increase in spaces between marks, but only up to a certain limit. The optimum spacing between main marks is 12.5-18 mm (with observation from a distance of 750 mm). Further increase in spacing worsens instrument reading.

An increase in number of small marks lowers reading speed and accuracy. The optimum size of the smallest spacing is about 1.5 mm or 6-8' (with observer 750 mm away). When the spacing is increased from 3.5' to 6.5', there is rather intensive increase in accuracy and time of errorless reading. However, further increase in spacing (to 10.5') does not result in appreciable improvement.

If the instrument pointer stops between marks on the dial, it becomes necessary to perform visual interpolation. Best interpolation results are observed when the operator has to mentally divide this space into no more than 4-5 parts.

The correlation between diameter of the dial and reading accuracy is not linear. The optimum diameter of a round dial is 40-60 mm (at a distance of 750-900 mm from the operator's eyes). However, there is no appreciable difference in reading accuracy with dials 35 to 70 mm in diameter. When the diameter is decreased to 17-18 mm or less, there is significant decrease in reading speed and accuracy. The same is observed when the diamter is increased to 120-150 mm.

Reading efficiency is not determined by the absolute diameter of the dial, but by its relation to observation distance, i.e., angular size of the dial. The optimum angular size of the dial diameter is in the range of 2.5-5°.

The best dials are those with 1, 5 and 10 graduations and corresponding numbering. The length of the numbered marks should equa_ 0.5-1 time the length of the space between marks, and the length of unnumbered marks should be half the length of the main marks. The thickness of the main marks should constitute 5-10% of the distance between unnumbered marks--two-thirds the thickness of the main marks [?].

The numbers should be inscribed on the dial in straight lines and only for the main marks. They should be simple, without any ornamentation. Accuracy in reading numerals depends on the proportion between height, width and thickness of outline. The latter is affected by light and contrast: the optimum correlation between thickness of outline and height of numerals under diffuse illumination is 1:10 for white digits on a black background (negative contrast) and 1:6 for black digits on a white background (direct contrast) under the same light. The distance between numerals should be half their width.

The arrangement of pointers and arrows [needles, indicators] is important when taking readings from dials: the pointer should go up to the smallest mark on the dial without covering it (minimum distance between the tip of the pointer and mark is at least 0.4-0.8 mm and maximum no more than 1.6 mm), and it must be as close as possible to the plane of the dial to reduce parallax to a minimum; the pointer should be simple in design, and its tip should be no larger than the width of the smallest mark on the dial; it is recommended that the part of the pointer between the center of rotation to the tip be of the same color as the marks on the dial, while the rest should be of the same color as the surface of the dial; pointers for linear dials should be distinctly visible; they are made rather broad at the base, but they narrow down toward the end facing the dial, changing into a clearly visible point; the pointers should not block the numerals; it is also desirable for the numerals to be placed on the outside of the dial.

If the pointers of compactly arranged dials are oriented in the same direction in normal position, any deviation of the pointer from its normal position is immediately detected, and considerably less time is required to check readings than if the pointers are oriented in different directions.

Operator efficiency increases significantly with the use of additional signaling devices. For example, when the "normal" range is indicated on the dial by a color band, it is enough for the operator merely to perceive and assess the reciprocal positions of the pointer and signaling device to make a check reading. The signaling mark used to draw the operator's attention must differ from other marks on the dial, not only in color but form. In some cases, the additional signaling devices should be movable. This permits an appropriate change in position of the mark when the "normal" range changes. It is also desirable to use colors for different parts of the dial, provided that the instrument is not lighted with a colored lamp.

Dials located along the edges of very large panels are furnished with signal lights; it is desirable for the brightness of these lights change with deviations from normal.

Thus, when designing pointer indicator devices, one must take into considration the following requirements: the pointer indicators must be installed on the panel in a plane that is perpendicular to the line of vision; the numerals should be simple and inscribed vertically on dials; the value of digital readings on round dials increased in a clockwise direction; the dial graduation should not be smaller than required by the precision of the instrument proper; dials with 1, 5, 10 scale divisions are the best; for dials installed on one panel, it is necessary to select the same system of divisions and the same numerals; when designing the pointers, parallax should be reduced to a minimum; the tip of the pointer cannot be wider than the smallest division, so as not to block the numerals and marks; for simultaneous check reading of several instruments, the pointers are so installed as to point in the same direction under normal operating conditions; to facilitate check reading, the working and overload ranges are distinguished by colors; the background of the dial must be dull, and there must be no light spots on the sides of the instruments; the surface of the dial should not be darker than the panel, whereas the housing of the dial can be darker; maximum contrast must be maintained between the color of the dial background and color divisions and marks.

There should be uniform illumination of the dial, while the degree of illumination must be regulated.

Other indicator devices: In addition to those with pointers, direct reading counters, printing devices and plotters are used.

Direct reading counters are used to obtain quantitative data, when rapid and accurate display is required. Counters should be placed as close as possible to the surface of the panel to reduce parallax and shadows to a minimum, and to provide a maximum angle of visibility.

If the observer needs to read off numerals successively, they should follow one another at a rate of no more than two per second. To increase counter readings or clear it, it is recommended that one use a reset or clear knob in a clockwise direction. Counters used to display the the sequence of equipment operation should clear themselves automatically upon completion of the work. There must also be provisions for the means of manual clearing.

If possible, counters should have their own illumination, while the surface of counter barrels and surfaces around them should have a finish that reduces to a minimum any reflection. It is desirable to have high color contrast between digits and the background (black numerals on a white background, or vice versa).

Printers are used when it is necessary to record quantitative data. The printed information must be suitable for immediate use with minimal need for decoding, substitution or interpolation.

Printers should be so designed as to provide for simple and rapid input and output of printed material. There must be reliable indication of supply of material (for example, paper, ink, tape). When necessary, the printers should be so placed as to make it possible to make various notes and marks on the tape without removing it from the recorder. The information should be printed on the tape in such a manner that the tape could be torn off as it is fed out of the device without using scissors or having to paste different parts thereof together.

Plotters are used to record continuous graphic data. The lines plotted must be easily visible, and they should not be obscured by the pen or its lever. The contrast between the tracing and background should be at least 50%. A special receptacle is provided, when necessary or desirable, for the paper with plotted data coming out of the plotter. The operator should have some ancillary equipment (for example, graph paper) to interpret graphic data; however, such equipment should not block or distort the obtained data. When necessary, the plotters are placed in such a manner that the notes and marks can be made on the plotted information without removing the paper from the plotter.

7. Integral Displays

The engineering psychological research on the performance of control system operators, which has been conducted in recent years, revealed that there are certain difficulties that arise when working with visual displays.

The methods of presenting information on large groups of individual instruments, even when they are quite modern and rationally arranged, that are in current use are not optimal. This is attributable primarily to the necessity of combining quantitative evaluations of a large number of different readings with qualitative assessment of situations, the parameters of which are displayed on the instruments.

One of the means of solving this problem is to use integral displays, which combine information about several parameters together of a given process or situation. This saves space on the panels and gains in perception accuracy and speed.

The distinctive features of integral displays are as follows: they provide a qualitative evaluation and permit graphic comparison of estimated data to real ones, thus permitting more efficient solution of control problems; maximum graphic presentation is provided by free movement of indices of parameters of actual operating mode or situation in relation to a specific scale; the direction of movement of an index designating the controlled object is compatible with the direction of the object itself; integral displays provide a fuller idea about the general situation, and for this reason the operator is able to predict development of a situation, rather than only record changes that are occurring.

It is also desirable to provide the operator with precise quantitative data to check the qualitative information presented on integral displays. The indicators of quantitative information should be located either on the periphery of the field of vision, or else they should function upon request (the latter method is preferable).

Development of new types of integral displays requires comprehensive psychological research on the means of information reception and processing by an operator.

8. Mnemonics

Mnemonics are information display devices that indicate conventionally the structure and dynamics of the object that is controlled and the control algorithm. Mnemonics are designed to perform the following functions: graphically display the functional and technological system of the controlled object and information about its state in the volume required for the operator to perform his functions; reflect the relations and nature of interaction between the controlled object, other objects and the environment; give signals about all important disturbances in operation of the object; provide for rapid detection of localization and elimination of malfunction.

Mnemonic equipment must contain only the elements necessary to the operator to monitor and control the object. The different elements or groups of elements that are the most essential to monitoring and control of the object should stand out on mnemomic diagrams according to size, shape, color or by other means. It is permissible to single out components of the controlled object that have autonomous control.

Mnemonic diagram layout should provide spatial conformity between location of elements on the diagram and location of control on the operator's console. It is permissible to place monitoring instruments and control elements on the margins of the mnemonic diagram, but they should not obscure from the operator's view other elements of the mnemonic diagrams.

An operator's customary associations should be taken into consideration in the arrangement of mnemonics. This refers to the association between conceptions that develop in man on the basis of prior experience. For example, an individual is used to depicting some process by describing its development from left to right. This customary conception must be taken into consideration in the mnemonics layout, and development of a technological process should also be shown from left to right.

The connective lines on a mnemonic diagram should be solid, simple in configuration and with the least number of intersections. One should avoid many parallel lines situated next to one another.

The form and size of mnemonic panels should provide unequivocal visual perception by the oeprator of all the necessary informational elements. Maximum angles of vision of the frontal plane of the mnemonic diagram should be as follows: no more than 90° from the vertical and no more than 90° from the horizontal (45° to each side of the normal to the plane of the mnemonic diagram).

If the mnemonic diagram goes beyond the zone circumscribed by the maximum angles of vision, it should be curved or consist of several planes (joined together or spatially separated) facing the operator.

The set of mnemonic signs used on one diagram should be developed as a single alphabet. This refers to a set of mnemonic signs that reflect a system of interrelated parts of the controlled object and characterized by unity of the descriptive rendition. The mnemonic alphabet should be as short as possible, while the distinctive features of mnemonic signs must be prominent.

Mnemonic digrams of objects similar in functions should be standardized as much as possible. The form of the mnemonic sign should be consistent with the main functional or technological features of the represented object. It is permissible to use as the basis the design of the object or its conventional designation as used in technical specifications.

The dimensions of mnemonic signs should assure the most unequivocal visual perception by the operator. The angular dimensions of a mnemonic sign of simple configuration should be at least 20'. These dimensions are determined with the following formula:

$$\tan\frac{\alpha}{2} = \frac{S}{2l}$$

where α is the angular size of the mnemonic sign, S is the linear size of the mnemonic sign and l is the distance from the mnemonic sign on the line of vision.

The angular dimensions of a complex mnemonic sign (with external and internal details) should be at least 35 angle/min, while the angular size of the smallest detail should be at least 6 angle/min.

Auxiliary elements and lines should not intersect the outline of the mnemonic sign or make the latter difficult to read in any other way.

The brightness of contrast between mnemonic signs and the background of the mnemonic diagram should be at least 65%. The value of the brightness contrast (K) is calculated as a percentage using the following formulas:

$$K = \frac{B_b - B_0}{B_b} \cdot 100,$$

and for negative contrast (the mnemonic sign is lighter than the background):

$$K = \frac{B_0 - B_b}{B_0} \cdot 100,$$

where K is brightness contrast, B_0 is brightness of the mnemonic sign and B_b is brightness of mnemonic diagram background.

Signals about changes in the status of an object (one-off, open-shut) should be distinguished by a particularly prominent color, shape or other feature. Special signals (warning, emergency, unscheduled change in status, etc.) should be more intensive (by 30-40%) than signals of normal operation, or they should be intermittent (at a flashing frequency of 3-5 Hz, the signal lasting at least 0.05 s). Combined use of both methods is allowed.

9. Panels for Group Use

A group use panel is a device that is designed to display information that is to be perceived by a group of operators from distances in excess of 4 m. A display in which signs are formed of different elements located in the same plane is called sign-synthesizing. The working surface of the display is the plane in which optical parameters are standardized and measured. The base sign is a digit rendered in a special way, which corresponds to the information relayed to the panel. The element is a component of the structural pattern of the indicator device. Noise immunity of the latter is a property that permits detection on the display of noise, manifested by disappearance of one of the elements forming a sign or appearance of an extra element, or else detection of noise by the operators and recognition of initial symbols when there is one missing or extra element. Digital sign-synthesizing electroluminescent displays are classified according to nature of noise immunity, subjective evaluation of quality of digit outline, color and brightness of luminescence, and magnitude of coefficient of reflection of the display's working surface.

Displays are divided into three classes, according to nature of noise immunity with single malfunction in the commutation* circuits: 1) displays that rule out the possibility of detection of noise and reconstruction by the operator of the base sign (5-, 6-, 7-, 8-, 9- and 10-element displays); 2) displays that permit detection of noise but preclude reconstruction of the base sign (6-, 7-, 8-, 9- and 10-element displays); 3) indicator devices that permit detection of noise and restoration of base sign (7-, 8-, 9- and 10-element displays).**

Indicator devices are divided into three groups according to subjective rating of quality of digit tracing: 1) usual outline; 2) satisfactory likeness to usual outline; 3) unusual outline, intended for educated and specially trained operators.

The indicator devices may have green, light blue, red and yellow luminescence. The green luminescent indicators are divided into seven groups, according to brightness (in cd/m^2): 1) 10, 2) 15, 3) 20, 4) 30, 5) 45, 6) 65 and 7) 90.

Displays with light blue, red and yellow luminescence are divided into six groups according to brightness (in cd/m^2): 1) 5.0, 2) 7.5, 3) 10.0, 4) 15.0, 5) 20.0 and 6) 30.0.

When the brightness of a display coincides with marginal values of two groups, it is referred to the lower group.

The displays are divided into six groups according to magnitude of coefficient of reflection of their working surface: 1) displays with a reflection coefficient in excess of 0.30, 2) those with coefficients of 0.30-0.20, 3) those with coefficients of 0.20-0.10, 4) those with coefficients of 0.10-0.06, 5) those with coefficients of 0.06-0.03 and 6) displays with reflection coefficients of less than 0.03.

*A single malfunction in commutation circuits refers to distortion of code combination of the controlling signal, which leads to lighting up of one element that is not contained in the sign to be reproduced, or to extinction of one of the elements that is part of the reproduced sign.

**The indicator devices may be executed with a decimal sign (point, comma), which is not included in the number of elements.

The type of display is characterized by its structural pattern, which displays an image showing the number, form and mutual location of elements of which the signs are formed.

In one type of display, there can be one or several types of digit outlines, which refers to the aggregate of 10 structural patterns of digits from 0 to 9 in this type of indicator. The type of digit outline is determined by the means of forming digits from the elements.

Indicator devices may have digits arranged vertically or slanted. The angle of inclination should not exceed 10° from the vertical position.

The format of the digits is determined by the ratio of sign width to height. The ratio of sign width to height should be 2:3. The minimal distance from the outer edge of the sign to the inner edge of the indicator housing is at least 5 mm with vertical position of digits and at least 2.5 mm with slanted position. The decimal sign should be to the right of a digit.

Noise immunity of the displays is determined by the type of digit outline. On class 2 displays, the types of digit outlines should make it possible to combine elements in such an order that the structures of distortions* appearing on the display with a single malfunction in the commutation circuits would differ from the structure of normally displayed digits** in one or several elements.

Specially trained operators should do the job of reading information from class 2 and class 3 displays when it is necesssary to reliably detect noise, or reconstruct base information (intended for display on the panel). A special method should be used for their training.

Conditions must be provided for optimum perception of information, and sign contrast must constituted at least 70% for reliable detection of noise by trained operators working with class 2 indicators, as well as for reliable detection of noise and restoration of base information on class 3 indicators.

Perception of information from the indicator devices is determined by several parameters. The following are among the main parameters that provide optimum perception conditions: brightness of the size and its dimensions; sign contrast; external illumination; observation distance; angle of vision; correlation between brightness of luminescence of working and nonworking display elements; uniformity of brightness of luminescence

*Structure of distortion--structure of image appearing on display with a single malfunction in commutation circuits which is not intended to display [light up] information.

**Structure of normally displayed sign--structure of image of sign intended for display of information.

of different elements within one display and different displays within the entire information field of the panel; color of display; coefficient of reflection of display's working surface.

Contrast between the sign and background should constitute at least 60%. Estimation and measurement of contrast should be made using a special method.

Table 7.

Display group No	Brightness (cd/m) of displays with green light: nominal brightness cd/m²	green light: allowed brightness cd/m²	light blue, red & yellow: nominal brightn. cd/m²	light blue, red & yellow: allowed brightn. cd/m²
I	10	8—12	5,0	4,0—6,0
II	15	12—18	7,5	6,0—9,0
III	20	18—24	10,0	9,0—12,0
IV	30	24—36	15,0	12,0—18,0
V	45	36—54	20,0	18,0—24,0
VI	65	54—78	30,0	24,0—36,0
VII	90	78—108	—	—

The minimal angular size of the sign should be at least 12 min, and the maximum no more than 46 min. The maximum angle of vision with digits 46 angle/min in size should not exceed ±50° and with digits of 46 angle/min it should be ±30°.(the symbol ± refers to any opposite angles of vision in relation to the line perpendicular to the display work surface).

Permissible irregularity of luminescence brightness of different elements of the same display should not differ from nominal value by more than ±10%. Special methods should be used to estimate nonuniformity of luminescence brightness of elements of the same display and of different displays on the panel.

The brightness allowance is unrelated to the color of luminescence on the display. The permissible deviations of brightness from nominal levels should conform with those listed in Table 7.

Optimum perception conditions are provided with the parameters listed in Table 8. Levels of illumination and angles of vision that are lower than those listed in this table, as well as higher brightness, do not impair optimum perception conditions, so that they can be used in the design and operation of group use panels.

With color coding of information, brightness of displays in green luminescence should not exceed the brightness of displays with blue, red and yellow.

The permissible correlation between brightness of working and nonworking display elements should be at least 7-8-fold. The permissible correlations between brightness of functional and nonfunctional display elements should conform with the data listed in Table 9. The brightness levels for nonfunctional display elements listed in Table 9 are also permitted with higher levels of external illumination and brightness of the sign.

Table 8.

Linear digit size (height), mm	Observation distance, m	Angular size of digit (height), mm	Permissible angles of vision, degrees	Displays with coefficient of reflection of working surfaces of 0.60: minimum brightness of display, cd/m²	0.60: maximum illumin. in display plane, lx	0.30: minimum brightness, cd/m²	0.30: maximum illumin. in display plane, lx
40	3—6	46—23	±50—45	30	100	20	150
40	6—9	23—15	±45—40	30	100	20	150
40	9—12	15—12	±40—30	30	100	20	150
80	6—12	46—23	±50—45	30	100	20	150
80	12—18	23—15	±45—40	30	100	20	150
80	18—24	15—12	±40—30	30	100	20	150

Table 9.

Permissible brightness of nonfunctional elements of display, cd/m²	Minimum brightn. of sign, cd/m²	Minimum illumination in display planes, lx	Observation range, m	Digit size (height), mm
3	20	50	3—12	40
4	30	50	3—12	40
5	40	50	3—12	40
3	20	50	6—24	80
4	30	50	6—24	80
5	40	50	6—24	80

Brightness and contrast of displays with green, light blue, red and yellow luminescence used in the same panel should be equal.

The levels of display brightness listed in Table 7 can be lowered with decrease in external illumination.

The allowable levels of brightness with different levels of external illumination should conform with those listed in Table 10.

Table 10.

Minimum brightness of display, cd/m^2	Maximum illumination in display plane, lx — for displays with working surface reflection coeff. 0.60	0.30	Minimum digit size (height), angle/min
30	100	200	12
25	85	170	12
20	75	150	12
15	40	80	12
10	30	60	12
5	15	30	12

Illumination levels below those listed in Table 8, as well as higher levels of brightness, do not impair optimum perception conditions, and for this reason they can be used in the design and operation of group use panels, along with those described. The brightness levels of displays listed in Table 8 can be lowered, while illumination can be increased with decrease in coefficient of reflection of the working surface of the display.

Permissible levels of brightness and illumination with different coefficients of reflection of the display's working surface should conform with those listed in Table 10.

Illumination levels below those listed in Table 10, as well as higher levels of display brightness, do not impair optimum perception conditions, so that they can be used in designing and operating group use panels, along with those indicated.

The value of the coefficient of reflection of the working surface of the display should be determined by a special method.

The general specifications for the panel are determined by the aggregate of specifications for operation of panels and control equipment.

The use of 5- and 6-element class 1 displays is permitted in panels, the main requirement of which is a minimum volume of control equipment, no requirement of noise immunity against a single malfunction in commutation circuits, with satisfactory or unaccustomed digit outline allowed.

Use of 6- and 7-element class 2 displays is allowed in panels, for which it is necessary to detect noise, with a limited volume of control equipment and satisfactorily customary digit outline.

Table 11.

Coefficient of reflection of working surfaces of display	Minimum brightness of display, cd/m²			Minimum size of sign (height), angle/min
	10	7.5	5	
	maximum illumination in plane of display, lx			
0.20	100	75.0	50	12
0.10	200	150.0	100	12
0.06	350	260.0	175	12
0.03	700	520.0	350	12
0.01	2000	1500.0	1000	12

Use of 8-, 9- and 10-element class 2 displays is allowed when they have to detect noise in the case of customary digit outline, and there is no rigid limitation on volume of control equipment.

Use of 9- and 10-element class 3 displays is allowed when it is of first and foremost importance to be able to detect noise and restore initial information with customary digit outline, and there are no rigid restrictions on volume of control equipment.

Displays with digits 40 mm in size are used in panels designed for reception of information at distances of 3 to 12 m. Displays with 60-mm digits are used in panels designed to perceive information at distances of 4.5 to 18.0 m. Those with 80-mm digits are used in panels for perception of information at distances of 6 to 24 m.

The distance between lines on the panel, measured vertically from the bottom edge of a sign on the top line to the top edge of a sign on the bottom line, should be at least 1.0-1.5 times the height of the sign.

The distance between columns, measured horizontally from the side of the sign in one column to the side edge of a sign in the next column, should be no larger than the width of the sign.

To color code information, one can use displays with green, light blue, red and yellow luminescence. The brightness of the sign and contrast on the displays used must be equal.

It is recommended that displays of only one group of brightness for each group of lighting color be used in the panel. It is permissible to use different brightness groups in the panel, provided the brightness of the panel is in the range of one brightness group. When it is necessary to provide brightness coding of displayed information, it is permissible to use indicator devices referable to different brightness groups in the same panel. The light sources should not produce high-lights on the working surfaces of panel displays.

10. Methods of Three-Dimensional Display

Spatial features of a situation are extremely inexpressive in information display technology. On the basis of these features or some a priori information, operators have to themselves supplement a two-dimensional image of a situation with their own conceptions of space, in which the controlled objects are or move. Of course, these conceptions are characterized by more or less (more often the latter) completeness from the standpoint of consistency with control problems.

Reports are being published more and more often about the search for development of three-dimensional indicator devices [17, 18]. At the present time there are numerous projects aimed at development such indicators, ranging from the simplest variants, for example, a mechanical device for tracing in three dimensions, where two pens with different ink are used for two dimensions and depth, i.e., change in distance between pens, is used for the third [3], to the most complex, for example, holographic methods of displaying information.

Three-dimensional indicators are divided into three main groups: 1) three-dimensional, 2) "illusory" and 3) graphic [figurative], although only the first is really three-dimensional, as it reproduces the width, height and depth [21]. Graphic indicators are the simplest of these groups; these are ordinary two-dimensional displays, in which symbols are used to designate the third dimension.

In illusory displays, only two dimensions are used, while the impression of three dimensions is created by means of a stereoscopic effect. Such indicator devices may be panoramic, and with double images. A promising means of three-dimensional display using double images is "xography" [?] which makes it possible to take photographs and print objects with reproduction of depth. The xographic process consists of using a special camera and grid placed before the film, which divides the image into several vertical bands. After the usual developing and printing, the film is covered with several special plastic strips, which allow the observer to view a different image with each eye, which creates the three-dimensional effect.

Special indicator devices are used in the first [three-dimensional] type of indicators for three-dimensional reproduction: cathode-ray tube with oscillating screen, which permits reproduction of the depth image; systems that create ionization of gas [typo for eye?], local excitation of which occurs at the required points of the three-dimensional coordination matrix; three-dimensional histograms.

Each of the above methods has a number of flaws: electromechanical problems related to attachment of the screen; difficulties related to implementation of memory and commutation, possibility of rapid change in information--all this creates certain difficulties with regard to use in systems of display of information.

One of the modern promising methods of three-dimensional display is holography, a process of photographic recording of the interferential picture that yields a three-dimensional image of an object as a result of separation of the laser beam into two parts, one of which illuminates the film directly (reference beam) and the other, the object, light waves from which are reflected on the film, combining with the light wave of the reference beam. When the developed photographic plate is exposed to laser beams, there is reconstruction of the image of the original picture with all its depth. The impression of three dimensions is so real that the observer tries to touch the reflected object with his hands. A hologram can reproduce equally well both distant and close objects. The remarkable property of holograms is that when they are illuminated the impression of reality of the viewed image is obtained; moreover, by changing his position, the observer can look beyond objects in the foreground, just like perception of a real picture. Use of holography is the most effective for display of information about separate objects or small groups, when highly accurate reproduction is required.

As compared to the design of more and more refined display devices, the planning and designing of control elements for three-dimensional display systems are considerably behind. We have no competent enough engineering-psychological and ergonomic evaluation and expert rating of newly developed control elements. As a result, there is an inconsistency between the latest display devices, such as three-dimensional ones, and control elements.

When working with cathode-ray indicator devices for solving problems of detection, recognition and tracking, three types of devices are generally used: 1) light pen, 2) control knob and 3) ball-type control [regulator, adjuster].

A light pen is a photoelectric sensor that serves to read information directly from the display. The main advantage of this device is the speed of reaction. The operator merely has to direct it toward the required point on the display and press the "on" button, while a computer that receives information from the light pen automatically determines the coordinates of the target. A light pen is used for approximate rapid determination of target position, when accuracy is not a critical parameter.

The control handle [or knob] is a lever that moves over two coordinates, X and Y. It is furnished with sensors that function in two modes: 1) rotation (the track on the screen moves in the indicated direction at a constant speed), 2) proportional movement (the track moves over a distance that is proportionate to the displacement of the control).

Displacement of the knob is initiated on the screen by the movement of a special symbol (echo signal) that shows the operator which part of the screen corresponds to the position of the control element. The control knob can move at high speed over a relatively long distance.

The ball-type control is a device that can turn in any direction to move the echo signal on the screen. Work with this type of regulator is considerably slower than with a light pen or control knob, but the results are more accurate.

11. Audio Signaling Devices (Nonverbal Messages)

A signaling device is an indicator intended to display information when it is necessary to specially attract the observer's attention. Audio signaling devices for nonverbal messages include sources of sound used at the work place for alarm, warning and informative signals (for example, a one-dimensional message; a short message; message requires immediate action; the place for receiving information is too light or too dark; increased accelerations; the operator's visual analyzer is busy, etc.).

The main technical characteristics of the audio signals for nonverbal messages are listed in Table 12.

Audio signaling devices for nonverbal messages must serve the following purposes: attract the attention of a working operator by means of delivery of an unexpected signal, change in level of sonic pressure, frequency and level modulation of sonic pressure, increased duration of sound, recurrence frequency; inform the operator about malfunction or change in the man-machine system; it should not overload the acoustic analyzer of a working operator; it should not distract other operators; it should not hinder verbal communication; it should not tire a working operator, deafen him by increase in level of sonic pressure of the signal, and it should not startle him by its unexpected appearance, which could lead to impairment of operator performance.

If there is a manual shut-off for the audio signaling devices, there must be provisions for automatic rest of the circuit to the initial poisition for delivery of the next control signal.

The frequency characteristics of tonal signals should be in the range of 200-5000 Hz. In the presence of high-frequency masking noise, the range can be expanded to 10,000 Hz. If there are acoustical screens in the control room, the recommended frequency of tonal signals is in the range of the 200-1000 Hz band. With changes in tone frequency, the rate of the change should be at least 3% of the base frequency.

Table 12.

Type of audio signaling device	Sound pressure dB	Frequency, Hz	Masking by noise	Design features features
Generator	50-120	200-5000	Mild with correctly chosen frequency in relation to masking noise and exceeding masking threshold	Can be used in internal communication devices
Buzzer	50-60	200-2000	Same as above	Same as above
Horn	30-100	200-5000	" " "	Can be with directional action
Siren	80-110	200-5000	" " "	Same as above
"Revun" [loud siren]	90-110	200-5000	" " "	" " "
Whistle	80-100	200-5000	" " "	May have a loudspeaker for directional transmission
Bell	60-90	200-5000	" " "	--

Warning and alarm signals must be intermittent. The carrier frequency of warning signals should be 200-600 Hz, with 1-3 s duration of signals and intervals between them. The carrier frequency of alarm signals must be 800-2000 Hz with 0.2-0.8 s intervals.

The sound pressure of signals at the entrance to the human external auditory meatus must be within the useful dynamic range, i.e., 30 to 100 dB. In the presence of masking by noise, the maximum permissible levels of sonic pressure of signals should be 110 to 120 dB (see Table 13). With changes in sonic pressure, the rate of change should be at least 3 dB. The sonic pressure of alarm signals must not exceed 100 dB. That of warning signals should not exceed 80-90 dB. Sonic pressure of informative signals should be lower by at least 5% than the sound pressure of alarm signals.

The duration of separate signals and intervals between them must be at least 0.2 s. With change in duration of audio messages, the changes should be made at the rate of at least 25% of the initial time. Loud audio signals should not last more than 10 s.

Table 13.

Frequency range of tonal signal, Hz	Maximum permissible sound pressure of signals, dB	General sound pressure of signal should exceed acoustic noise by at least indicated value, dB
200–800	120	10
800–2000	115	13
2000–5000	110	16

Signals should be modulated by changing amplitude and frequency. With amplitude modulation, the depth of modulation should be at least 12%. With frequency modulation, the depth of modulation must be at least 3% of the carrier frequency.

In the presence of masking by noise, audio signals are used, the frequency of which is as different as possible from the most intensive noise frequency. It is necessary that the threshold of the audio signal masking be exceeded by 10 to 16 dB (Table 13).

In the case of masking by tonal signals, one uses audio signals whose frequency differs as much as possible from the frequency of the masking tone.

12. Verbal Warning Signals

These signals consist of an initial alert signal (nonverbal) to attract attention and identify the general problem, as well as a brief standardized verbal signal (verbal message), which identifies the concrete conditions and suggests appropriate action.

For critical functions, the level of verbal alarm signals must be at least 20 dB above the noise level at the location of the operator receiving the signal.

The voice used to record verbal warning signals must have good diction and be well-developed. Verbal warning signals are given in a formal, neutral and calm voice. The words must, in the first place, be distinct; in the second place, they must conform with the meaning of the situation (conditions) and, in the third place, they must be brief.

Critical warning signals should be repeated at intervals of at least 3 s until the situation is corrected.

The system of verbal warning must have a mode interlock executed in a manner so as not to permit transmission of messages that have no meaning to prevailing conditions.

The volume of verbal warning signals should be regulated by the operator or an automatic device, with due consideration of working conditions and operator safety factors. There must be limited movement of the volume regulator, so that any signal is audible to the operator.

There are means of manual setting and adjustment of volume in the system of warning signals. Audio warning signals should last at least 0.5 s, and continue until there is an appropriate reaction (corrective action) by the operator or automatic equipment. Completion of the corrective action should automatically stop the signal.

In emergency situations, one should not use signals that remain on or are amplified, if turning them off could hinder the necessary corrective action.

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CHAPTER VIII. OPTIMIZATION OF WORK MOVEMENTS AND CONTROLS

1. Optimization of Work Movements

When developing the scientific foundation for designing the means of human work in man-machine systems, both Soviet and foreign ergonomics and engineering psychology concentrated chiefly on development of specifications for information models and means of displaying information, with considerably less attention being given to development of requirements for control elements, which refer to elements of the work place designed to transmit control action from man to machine. For integral solution of this problem, it is equally important to design both modern means of information display and controls, with due consideration of ergonomic requirements.

The nature, sequence, speed and rhythm of work movements are largely determined by the form and construction of instruments, controls, machines and other equipment, as well as organization of work places. For this reason, in designing and organizing them, it is imperative to take into consideration the following rules for economy of movement: when working with both hands, their movements should be simultaneous, symmetrical and opposite in direction as much as possible. Simultaneous and symmetric movements provide for equilibrium of the entire body, which facilitates performance of work; the planned movements should be simple, smooth and rounded; one must use the fewest movements to perform the work operation; the trajectory of work movements should not exceed the work zone; movements must conform with the anatomical structure of the body and they should be performed within the zone of visual inspection to the extent this is possible. Each movement should end in a position that is convenient for the start of the next movement, and successive movement should be smoothly interrelated; movements should be not only simple, but rhythmic. One should not allow rhythms that are too slow or too fast. It should be also borne in mind that "so-called 'nonrhythmic' movements are not movements without rhythm, but movements that deviate from the set rhythm or else unrational movements that affect the rhythm" [4, p 66]; the movements must be customary to the worker. When learning a new operation or becoming familiar with new equipment, one should take into consideration the distinctions of prior developed skills of the worker; it is imperative to provide conditions, under which small muscle groups would be used to overcome low resistance and large muscle groups would become involved in the presence of significant obstacles; one should make the utmost use of kinetic energy of the object of work in order to reduce muscular work.

One should not design equipment elements that require great physical force or an unrational work position. Thus, a worker should not have to hold his hands above his head for any length of time, since this would very rapidly lead to fatigue. Poses when the worker has to lie on the ground, bend over or stoop are also very tiring.

When designing equipment, it is necessary to make provisions for rational work movements. For this reason, one should design work tools that are adapted to a maximum extent to the energy, strength and velocity characteristics and capabilities of man.

In order to assure rational work movements, it is imperative to eliminate from the work process superfluous, inefficient and tiring movements and actions, such as shifting work objects or tools from one hand to the other, constantly supporting a part with the hands while working on it, superfluous bending, turning, stooping and other unnecessary movements that cause premature fatigue, and of all the possible movements one should choose the shortest in trajectory and those requiring minimal effort.

When designing equipment, one must take into consideration certain rules and theses pertaining to velocity and accuracy of work movements, as well as economy of work effort, which are related to the physiological, psychological and anatomical distinctions of man.

The speed of work movements involves the following considerations: movement toward oneself is preferable when a rapid reaction is required; the speed of hands is greater in the horizontal plane than in a vertical direction and maximum speed of movements is downward, while the minimum is away from oneself and up; the right hand moves faster from left to right than in the opposite direction; right hand movements are faster than for the left hand; the speed of movement at an angle to the vertical and horizontal planes is lower than on these planes; rotating movements are faster than forward movement; movements with a wide sweep are faster; smooth, curved hand movements are faster than in straight lines with abrupt change of direction; the speed of movement decreases with increase in load; movements guided by mechanical devices are faster than those guided visually; movements with one hand are performed at highest speed at an angle of 60° to the plane of symmetry, and with both hands at an angle of 30°; the maximum rate of rotating movements is 4.0-4.8 r/s; depressing movements constitute 6.6 depressions per second for the preferred hand and 5.3 for the other. Maximum rate of striking movements is 5 to 14 strokes/s and the optimum for lengthy work is 3.5-5.0/s.

With respect to accuracy of movements: accurate movements are performed better in seated than standing position; greatest accuracy of movement is obtained in the horizontal plane in the zone 15-35 cm away from the midline of the body, with 50-60° amplitude of movement in the elbow; accuracy of placing the hand on a set point constitutes 15-20 cm in the middle zone below the chest and 30-40 cm in the extreme zones; when working without seeing ["blindly"], short distances in the horizontal plane are overestimated by man while long ones are underestimated; in the vertical plane they are overestimated; movements with an amplitude of 8-12 cm are rated the most accurately; there are fewer errors in movements in the vertical plane than the horizontal. In this respect, the best directions of movement are upward to the left and downward to the right at an angle of 40° to the horizontal plane; the accuracy of movements of both hands with the optimum amplitude of movement for each is the same, but the optimum amplitude is not the same for both arms: for the right hand the amplitude is 4-5° wider than for the left; spatial accuracy of movements is best with a small load (up to 25% of the maximum effort) and it diminishes with significant ones.

The correlation between spatial accuracy of movements and their speed is as follows: for rotating movements the accuracy is best at a rate of 140-200 r/min and for striking movements, 60-70 movements/min.

Economy of effort: the force developed by the hand depends on its position: pressure and traction are stronger when the hand moves in front of the body than to one side of it; if both hands are used to work, one should bear in mind that the right hand is stronger than the left, by 10% for digital flexors and by 3-4% for flexors and extensors of the forearm; maximum effort [force] develops on the shoulder level in standing position and on the elbow level in seated position; maximum force in standing position develops for movement toward oneself; force of pressure is greater with the arm bent than extended; thrust [traction] in the horizontal plane is greater when making movements in front of oneself than on either side; pressure is greater than thrust in seated position; the force of forearm flexors is greater with the arm bent than extended; the force developed by the hand in seated position, when moving in different directions, is arranged in about the following order: pressure (horizontal), thrust (horizontal), movement up, movement down, movement toward oneself (on the side) and movement away (on the side); the force of arm rotation is related to its position and direction of rotation: greater force develops with inward turns than in the opposite direction; the force of leg pressure is greater when the legs are extended forward (with an obtuse angle in the knee joint) than with a right angle at the knee joint, in seated position.

It has been found in industrial psychology that movements are organized not only spatially, but musically, and they are governed by a certain rhythm. It was noticed at one time that the most skilled typesetters perform circular movements, which appear at first glance to be less purposeful than linear ones, when setting a line of type. Yet a circular (curved) line provides for greater continuity of rhythm and subordination of movement to a certain rhythmic structure. For this reason, in certain cases, it is not the fastest or the shortest movement that is the most rational. Demonstration of the corresponding patterns of organization of movement can be made only on the basis of in-depth psychological analysis of work.

2. General Requirements of Control Elements

Each type of executory (control) action by an operator has its own inherent biomechanical distinctions, which must be considered when selecting the construction and location of controls. For this reason, attention is devoted chiefly to controls that permit execution of decisions made by operators of automated systems, i.e., that permit manual input of information, request thereof on display and monitoring devices, determination of measured or counted values, as well as work with actuating elements of controlled objects (starting and stopping mechanical devices, switching operating modes, etc.).

Since various controls can be used to perform the same functions, one should take into consideration, in making a choice among such controls, convenience of operation, safety, technological effectiveness of construction, as well as principles of engineering aesthetics. Such considerations present a difficult problem, since parameters of controls that are being rated in this manner should, in addition, necessarily conform with anthropometric and biomechanical data. As a rule, the results of the aggregate evaluation are summed up [generalized]. On their basis, standards and normals are developed, although many of these results still remain on the level of general requirements.

The general requirements include the following.

Controls are selected with consideration of the fact that the direction of their movement corresponds to the direction of movement of the indicator device linked to it, element of equipment or means of movement. Forward movement of a control, in a clockwise direction, to the right or up, as well as depression thereof should correspond to turning equipment or an element thereof on, increasing the measured (counted) value, as well as movement of the equipment or its elements forward, clockwise, to the right or up.

Turning regulators of valves should open valves when turned counterclockwise. The controls for valves are equipped with two-way pointers showing the direction for closing and opening the valve in accordance with inscriptions (for example, "open," "closed").

If the controls are used in a certain sequence, they should be appropriately grouped. They should be so placed as to alleviate the operator's work (preserving the customary procedure for action, from left to right and top to bottom). Controls that are of particular importance and frequently used must be in the most convenient position with regard to reach and grasp. This applies primarily to revolving controls and those requiring fine setting (adjustment).

Controls used exclusively for technical maintenance and adjustment are referable to the category of seldom used ones; therefore they should be covered but, at the same time, easily reached.

Controls that perform similar functions are placed in a similar way on different panels. Controls used to perform the same functions on different panels should be of the same size.

The shapes of the controls should be easily identifiable, and they must not have any sharp edges.

The controls should also be convenient to use when working in mitts or gloves. For this purpose, there is additional specification of the size of control elements. If one has to work blindly, the controls must be coded by shape or at a distance of at least 12 cm from adjacent controls.

Control elements are designed and arranged in such a manner that they cannot be accidently moved. Special attention is given to critical controls, the careless or accidental movement of which could damage equipment, injure operators or worsen the system. Controls that are situated on the internal part of a panel or open controls should be protected against being tripped accidentally. The following is required to protect controls from accidental tripping, in accordance with specific conditions: the controls should be placed and oriented in such a manner that the operator could not accidentally touch or move them while performing his duties normally; shielding and other means of protection should be used; there must be reliable interlocking [or lock-out] for the controls; mechanical resistance must be created in the controls (i.e., viscous or coulomb friction, wire-load or inertia) so that a certain effort must be made to move the controls; there must be locks on the controls to prevent movement into a prohibited position; revolving construction of controls should be used.

An automatic brake, which automatically switches the system to a non-critical operating state in the case of removal of effort, is used in all instances when the operator is unable to perform the work and this could lead to a critical state of the system.

3. Requirements Referable to Different Types of Controls

Turning selector switches: They should be used for discrete switching, when three or more fixed positions must be obtained; they are not recommended for two-position switching (with the exception of instances when visual identification of position is of primary importance, while speed of switching is not critical). Switches that are always in the operator's field of vision should not have more than 24 fixed positions.

Turning [rotating] selector switches are equipped with a moving pointer and stationary dial. The moving pointer should be in the shape of a band with parallel sides and pointed tip. Form-coding of pointers can be used if there is limited space and small torque, as well as in cases where several rotating switches serving different functions are located on the same panel, which lead to confusion. One must also take into consideration the following conditions: where possible, the positions of a rotating switch should not be situated directly opposite one another; stops must be provided at the beginning and end of the range of changes in positions; the mechanical resistance of the switch must be smooth, first building up and then decreasing as one approaches the fixed position, so that the switch would be moved to the next position in a jump, without intermediate stops. The effects of friction and inertia should be reduced to a minimum.

A baseline is provided on turning selector switches. The contrast between this line and the color of the switch proper should constitute at least 50%. The switch pointer is placed rather close to the dial, to reduce to a minimum the parallax between the pointer and marks on the dial. During observation by an operator in his normal position, the error due to parallax should not exceed 25% of the intervals between marks on the dial.

When handling the switch, the operator should be able to see well the dial and pointer, and the divisions on the dial should not be blocked by his hand. If the switch handle is to the left of the operator and controlled with the left hand, the divisions on the dial and inscriptions are arranged above and to the right of the switch; if the handle is to the right of the operator and controlled with the right hand, the divisions on the dial and inscriptions are above and to the left of the switch. The marks for frequently used settings on the switch dial should be located on the part of the dial that is the most convenient to see. Turning selector switches should be located in the optimal work zone.

In the case of grouping several identical switches together, they can be distinguished better when the distance between groups is increased, with indication of functions performed with them, when other controls are placed between them.

Socket ["tortsevyye"] switches: These are recommended as a compact device for digital input-switching with concurrent reading of inputted digits for checking purposes. The use of such switches for any other purpose is not desirable.

Socket switches can have both discrete and smooth action, depending on their specific purpose. Each position on the socket switch corresponds on its circumference to either a slightly indented surface or segment of knurled surface that protrudes somewhat, as compared to the rest of the surface. Socked wheel-switches with smooth action should have knurling over the entire external surface.

Socket switches can be coded by position, marks and color (for example, using a different color for the wheel with the lowest digit, as in ordinary speedometers). When they are used as an input device, they should have color coding for the "on" and "normal" positions, to make checking and monitoring easier.

The design of a socket switch should permit visualization of the digits in a line from all work positions of the operator. Those with a discrete position are equipped with stops. The resistance of these stops should be smooth, first building up and then decreasing as the fixed position is reached, so that the switch would be set in the next fixed position without delay.

The distance between adjacent edges of socket switches should be sufficient to prevent accidental movement of an adjacent switch during normal operation.

Knobs: They are used when negligible exertion is required and one needs to make a precise adjustment of smoothly changing variables. If it is necessary to distinguish the positions for a knob that does not make many revolutions, a mark or indicator is provided.

When the size of a panel is extremely limited, the size of the knob should be as small as possible, and resistance to rotation should be as low as possible; however, their position should not change if they are touched accidentally.

Handles and flywheels: Handle generally refers either to part of any control that an individual grasps directly with the hand (handle of a tumbler, lever, crank, etc.), or to an independent control (handle proper). The shape of the handle varies significantly. It may be flat, elongated, in the shape of a "beak," etc. The typical distinction of these handles is that they are grasped with the fingers on either sides of the axis in order to turn them.

Handles proper are most often used for smooth or stepped adjustment of a parameter, to turn equipment on or off, as well as in the capacity of multiposition switches.

To incrase accuracy of control, resistance of handles to the operator's force should constitute 0.7-1.2 kg. When they are used, the operator should feel the transition from a fixed point (points), but the additional force at the time of transition should not exceed 10% of the base level.

The size of the handles depends on the force to be applied. Thus, for forces constituting 0.13-0.19 kg/m, the diameter of a handle is 75 mm, and for 0.19-0.25 kg/m it should be 100 mm.

The maximum diameter of a handle is 140 mm and the minimum is at least 12 mm. The recommended diameter of handles to be grasped with three fingers is 10-16 mm. Such handles permit rotation over 100-120° in a single grasp.

When rod-type handles are used for stepped changes, the minimal interval between positions should be 45° and there should be a stop for each position. One should gradually change the resistance of the stops from 0.06 to 0.01 kg/m when moving the handles from one position to another.

Handles that are used for adjustment and regulation, which do not require great accuracy, may be constructed in the form of keys operating on the principle of "more--less," provided the mean frequency of control actions does not exceed one action per 20-30 s.

Key handles are colored the same as the corresponding mnemonic sumbols. They should be installed on console panels in such a manner that the hands would not block inscriptions and indicators. For this reason, all designations and inscriptions should be situated above and to the right of the handle when the handles are on the left and controlled with the left hand, and above and to the left of the handles when they are located on the right and controlled by the right hand.

Crank handles are used chiefly when the control operations require performance of many revolutions, especially at high speed or with the use of great force. If necessary, crank handles can be installed on knobs or flywheels: the crank handle is used for rapid turns, while the knob or flywheel is used for fine adjustment. If crank handles are used for adjustments or other purposes requiring a choice of digits, each turn of the handle should correspond to values that are multiples of 1, 10, 100, etc. The crank handle should turn freely about its axis.

Flywheels designed for operation with two hands are used when the rotating force or shear moment are too great for operation with one hand; in this case, two knobs should be provided for the flywheel. To improve linkage with the operator's hand, the flywheel is knurled or ridged [grooved].

Flywheels should turn in a clockwise direction for "on" or "increase" operations and counterclockwise for "off" or "decrease." The direction of movement is shown on the flywheel proper, or in the immediate vicinity thereof by an arrow with appropriate inscription.

Buttons and keys: Buttons are used for rapidly turning equipment on and off, to input digital or logical information and commands, especially when these functions are performed often.

The surface of the button should be indented, corresponding to the structure of the finger, and ridged to prevent slipping. A square shape with rounded corners or rounded top edge is the most convenient for frequently used buttoms. Seldom used ones may be round. The construction of the button should enable the operator to feel or hear a click, or both. If accidental operation of a button could create an emergency situation, the button should be made deeper or a protective cover should be provided.

The normal position for keyboard buttons is at the operator's elbow level when he is in seated position (elbow bent at an angle of 90°, horizontal position of forearm).

It is desirable to place buttons on a panel that is tilted in relation to the table surface. The optimum angle of the keyboard of a button console is 15° from the horizontal plane.

The distance between adjacent buttons, with the exception of those used in a keyboard, should be at least 12 mm from edge to edge (at least 6 mm when working with one finger). The minimum diameter of buttons for which the index finger is used is 9 mm and for the thumb, 18 mm.

The force applied to frequently used buttons is 280-1100 g, and to seldom used ones, up to 1500 g.

The color of the buttons should be in contrast with the color of the panel: the buttons are light (white, gray or beige) on dark panels. If the background of the panel is light, the buttons should be a darker or brighter color.

A 10-digit keyboard is used for input of digital information, and each button on it serves to input one digit in the communication channel (computer). On the keyboard there is also a special "clear" button to cancel incorrectly set information. If the digital information intended for transmission is within the range of 10, the keyboard is installed horizontally and the "clear" button is on the right. But if it is necessary to transmit multidigit numbers, the buttons are arranged vertically in the form of parallel columns, so that the same digits are in the same horizontal row. This makes it possible to compose digits in categories of the decimal (or other used) system. The buttons should be numbered from top to bottom. The "clear" button is under the keyboard. The distance between columns should be at least as large as the diameter of a button.

A horizontal arrangement of the keyboard, with successive location of instructions from left to right, is recommended for input of logical or command information.

The link between instructions should be coded, usually by shape or color of buttons. Use of more than four colors is not recommended for coding. There must be a brief indication of inputted information or instructions on all buttons. Particularly important and emergency instructions are inputted with the fewest number of buttons. Such buttons are prominent in size, shape and color. They are located in the top part of the optimum work zone, apart from the rest of the buttons to avoid accidental contact.

Both buttons and keys can be used to turn equipment on and off, as well as to input information set on the keyboards in the communication channel or computer ("input" button) and to cancel incorrectly inputted information or instructions ("cancel" button).

The key (button) for "input" is located in the optimum work zone, to the right or below the keyboards, on which the transmitted information is set. The "cancel key"(button) is of the same size and shape as the "input" key, but different in color.

Buttons (keys) used to turn equipment on and off are placed on the console in accordance with frequency of use in the course of operational work. If the equipment is turned on and off only before and after work, the relevant buttons (keys) can be outside the work zone.

If there are many buttons on a panel or console, it is recommended that they be arranged in groups. The number of buttons per group, in both horizontal and vertical direction, should be a multiple of 5.

In the case of logical grouping of buttons and keys, it is recommended that buttons be placed under keys that are horizontally arranged, or to the right of keys arranged vertically.

Foot-operated buttons should be depressed with the pads of the toes, not the heel. If place allows, foot buttons should be replaced or supplemented with pedals that help locate the control. The work surfaces of foot-operated buttons must be grooved to increase friction. The construction of the button should be such that the operator would feel a click, hear a click, or that there is a photic or audio signal. One can use a foot-operated button or foot-operated lever to perform the "on" operation.

The following sizes are recommended for foot-operated buttons: optimum size 50-80 mm, and range in depth 30-50 mm.

The force required should be in the range of 2-9 kg. More than two foot buttons should not be used at the same work place.

Tumbler type switches and commutators: These controls are devices for commutation of electric circuits, which are actuated by moving the drive element from one fixed position to another with the operator's fingers.

Switches and commutators of the tumbler type are used for rapid "on" and "off" operations, and choice of range in cases when visual monitoring of switch position is required.

The shape and size of the drive element of tumblers should conform with anthropometric data for the human fingers and physiological properties; they should also provide utmost convenience of grasping the drive element in the process of control.

The drive element of tumbler type switches should be tapered or cylindrical (the cylindrical part at the end of a drive element can be executed in the form of a "ball" or "shovel"). In cases where coding is needed, the shape of the drive element can vary, but it must meet the requirements regarding applied force. Color coding on the end of the drive element is also permitted.

When the drive element is changed to another position, there must be feedback perceptible in the form of a "click."

The "up" and "right" positions of the drive element of tumbler type switches should correspond to the functional "on" state, while "left" and "down" positions should correspond to "off." When tumbler-type switches are arranged in a row, this row cannot be "vertical" or "in depth" of the panel, in relation to the operator.

Inscriptions and symbols must be used to identify the functions of drive elements of tumbler type switches. The inscriptions and symbols should be placed on the control panel in the immediate vicinity of drive elements, on either side, provided that the drive elements themselves, as well as the operator's hand, will not cover the designations during manipulation of drive elements.

Tumbler type switches are divided into two types, according to effort that has to be applied: "light," referring to exertion of up to 0.7 kg, and "heavy," for over 0.7 kg. The dimensions of the drive element depend on the force to be applied, and they should conform with those listed in Table 14.

In two-position switches of the tumbler type, the angle of displacement of the drive (on the mid line) from one position to another should constitute $40 \div 60°$, and in three-position ones, $30 \div 50°$.

Table 14.

Type of tumbler	Force, kg	Length of drive, mm	Diameter	Remarks
"Light"	0.2	10	3	Tumblers that are frequently used
	0.3	12	5	
	0.5	15	6	
	0.7	20	8	
"Heavy"	1.0	25	10	Tumblers for special uses
	1.5	30	12-15	
	2.0	35	15	
	2.5	45-50	18	

For a force in excess of 2.5 kg, one should use the "lever" type of switches. There must be no sharp edges or borders on the work surface of drive elements.*

When arranging tumblers on the control panel, the minimum distance between axial lines of drive elements must be 12 mm, and it must be 25 mm if working with gloves. If the drive elements are turned in opposite directions, their extremities must be at least 19 mm apart.

Keys with inscriptions: The following requirements apply for these controls: there must be a stop or catches for reliable indication of operation of a key with inscription; the inscription on the key should be well-readable under the light of only one lamp; there must be provisions to test light by depression; there must be spare lamps or incandescent filaments; the lights for keys with inscriptions should be changed from the front of the panel; covers with inscriptions should have guides to prevent the possibility of incorrect placement; no more than three lines are allowed on plates with inscriptions.

Levers: This refers to controls that are used for stepped switching and smooth, dynamic regulation with one or both hands.

The minimum length of the free part of a control lever (with its handle) should be at least 50 mm in any of its positions if it is to be grasped with the fingers and 150 mm, if grasped with the entire hand.

The shape and size of lever handles should provide maximum convenience in grasping them and reliably holding them in the control process. Preference

*The work surface of the drive refers to the section of its surface that comes in direct contact with the operator's fingers at the moment the mobile system of the switch or commutator is put into action.

is given to levers with smooth, rounded shapes (close to spherical and elongated cylindrical) with thoroughly finished smooth or ridged surface, without sharp corners or burrs. The handles of levers used at low ambient temperatures should be made of material with low heat condition, or covered with such material.

It is permissible to use control levers combined and integrated with other types of controls (steering wheel, button, catch, etc.) for simultaneous performance of several control actions (in more than two dimensions). Each of them must meet its own specific ergonomic requirements.

Control levers must be installed at the work place in such a manner that the handles thereof are within reach of the motor field of the operator, with due consideration of safety requirements, whatever the position of the lever. The handles of levers that are moved with one hand must be placed on the side corresponding to the working right or left hand, within reach, with a 90-135° angle of the elbow joint and application of force in a straight direction, to or from the operator. Lever handles that are moved with two hands are placed in the plane of seat symmetry with deviations not exceeding 50 mm. The direction of movement of the handle must be determined in accordance with the nature and distinctions of control, with adherence to conformity of direction of movement of the controlled object with the indicator reading.

In some cases, when using levers for accurate and continuous adjustment the following supports must be provided (in the presence of vibration, accelerations, jarring, etc.): for the elbow, when there are broad movements of the hand and forearm; for the forearm, when movements are made with the hand, and for the wrist, when movements are made with the fingers.

One should code control lever handles, including special purpose levers (to be used in case of emergency, fire, etc.), as well as levers combined in functional groups, by means of selection of suitable shape, size and color, as well as location. Control levers should have well-visible inscriptions showing their function, as well as indicators of position, direction of movement and results of movement, which are placed directly on the levers, as well as next to them.

Levers that are used for discrete (stepped) operations should have reliable immobilization for intermediate and end positions. If necessary, the end positions of a lever should have a special stop (support). Control levers should be so installed as to rule out the possibility of accidentally moving a neighboring lever when they are used.

The main sizes of control lever handles should be in the ranges listed in Table 15, according to their shape and how they are grasped.

Table 15.*

Handle shape	Diameter, mm				Height, mm			
	grasping with fingers		with hand		with fingers		with hand	
	range	optimum	range	opt.	range	opt.	range	opt.
Round (spherical, pear-shaped, tapered, etc.)	10-40	30	35-40	40	15-60	40	40-60	50
Elongated (spindle-shaped, cylindrical, etc.	10-30	20	20-40	28	30-90	50-60	80-130	100

*For pear-shaped, tapered and spindle-shaped handles, the largest diameter is given, and for spherical ones, only diameters.

Table 16.

How lever is moved	Frequency of use	
	more than 5 times/shift	less than 5 times/shift
	force, in kgf, no more than	
With the fingers	1	3
Hand	2	4
Hand with forearm	3	6
Entire arm	6(4)	15(7)
Both arms	9	25(14)

The figures in parentheses refer to force with "right-left" and "up-down" movements.

Pedlas: These controls are often used in the construction of work places of transport vehicles, when the operator's hands are occupied. A pedal can serve both to input discrete signals and for continuous regulation of parameters. When great accuracy is not involved, considerable force can be obtained with pedals.

Pedals are so designed that they return to zero position after discontinuing force on them.

When the angle of the pedal in relation to the horizontal plane is over 20° a heel rest should be used. Pedals should be covered with nonskidding material. Their width and length should be approximately equal to maximum foot size (in the appropriate shoes).

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